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EVALUATION OF SOLID WASTE BALING AND BALEFILLS

VOLUME I

RALPH STONE AND COMPANY, INCORPORATED

PREPARED FOR
ENVIRONMENTAL PROTECTION AGENCY

1975

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EVALUATION OF SOLID WASTE BALING AND BALEFILLS

VOLUMES I and II

This final report (SW-111c.1) describes work performed for the Federal solid waste management programs under contract No. 68-03-0332 and is reproduced as received from the contractor

Volume I reports on a one-year evaluation of a solid waste high-density baling plant and the associated transportation and sanitary landfill operation.

Volume II contains the technical appendices.

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1975

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ABSTRACT

This final report presents the results of a one-year evaluation of a solid waste high-density baling plant, transportation and associated land disposal operation of the American Hoist and Derrick Company in St. Paul, Minnesota. The work program consisted of four stages: (1) a five-day intensive monitoring program of the baling plant and bale transportation operations; (2) cost analysis during two years of plant operation; (3) a nine-month period of monitoring the St. Paul bale landfill operation; and (4) a 14-month period of monitoring a bale test cell constructed at the balefill.

The five-day monitoring program consisted of the following: time and motion studies of the bale plant using video tape and activity time charts; density measurement; sorting by component and laboratory analyses for moisture and organic content of the incoming solid waste; sampling and laboratory analyses for moisture and organic content of baled solid waste; sample volume measurement and laboratory analyses of liquid squeezed from solid waste during baling; compaction ram hydraulic pressure, bale production time, and time-phased measurement of dimensions on every tenth bale produced; bale weights; monitoring of the volume of incoming solid waste and the number of incoming vehicles; and measuring the travel time, distance travelled, number of bales per load and activities of the trucks and drivers transporting the bales to the landfill. Photographs were taken to illustrate the baling operation activities.

Analyses were completed of the reliability, interference and utilization of equipment and labor in the bale plant and transport operations separately, and for the bale plant/transport/landfill system as a whole. Standard MTM analyses were completed for tasks to define labor efficiency and human factors parameters. The density and springback in every tenth bale were determined as a function of time. Limited time studies were made of transport truck rigging operations. Operation and amortization costs are presented for a two-year period covering 12 months of historical data from July 1972 to June 1973, and data during the contract through closing of the baling plant in June 1974.

Landfill operations were monitored weekly over a nine-month period for bale spacing, surface water, broken bales, cover soil quantities and depth, litter, dust, vectors including fly emergence, time and motion studies of landfill equipment operation, photographs and samples of water from a well located in a completed landfill area.

A test cell was constructed at the bale landfill and filled with bales produced during one week of baling plant operation. Gas, temperature, and settlement probes, leachate collection membrane, sump, and lysimeters, were installed in the test cell which was covered woth six inches of soil to duplicate the regular bale landfill. Weekly monitoring over a 12-month period consisted of temperature (daily during the first two weeks), gas, leachate from a leachate collection system and probe lysimeters, and surveying for settlement.

Analytical comparisons were made between the bale landfill and normal landfill environmental conditions. The feasibility of solid waste high-density baling plant, transportation and landfill operation was evaluated and compared to milling, combined milling and low-pressure solid waste baling systems and conventional solid waste systems.

The data in this report are presented in metric units with some English units in parenthesis. A conversion table is included.

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SUMMARY OF FINDINGS

In accordance with the Scope of Work outlined in EPA Contract No. 68-03-0332, the following results and findings are summarized for the five-day baling plant survey and long-term monitoring program.

A. Baling Plant and Operations.

1. The labor force at the baling plant consisted of eight employees: one gate attendant, one loader operator, one forklift operator, one maintenance man, two cardboard sorters, one control tower baler operator, and one plant foreman.

2. Stationary equipment at the baling plant consisted of one horizontal and one inclined conveyor, a load-cell scale, a high-density 137-second-cycle baler, a central control tower with control panels, two hydraulic bale push rams and a bale truck loading platform.

3. Mobile equipment used at the plant consisted of an articulated front-end loader, a small general purpose "bobcat" loader, and a forklift.

4. The front-end loader mixes and pushes waste onto the horizontal conveyor; the conveyors carry solid waste to the baler, which consists of three hydraulic rams and a baling chamber. Two hydraulic pushers move completed bales onto a flat-bed truck. Fourteen to sixteen bales were loaded on a single truck. The small "bobcat" loader was used to pile corrugated material and for cleanup; the forklift was used to remove bales not going to the landfill such as corrugated cardboard and metal.

5. Minor quantities of dry, residual bale particles and liquids squeezed from the wastes were observed to collect directly below the baler and on the vertical tramper ram tower walkway and ram framework. Liquid wastes were observed to occasionally squirt onto the control tower concrete supports.

B. Nature of Incoming Solid Waste.

1. Peak period for incoming solid waste was 9:00 A.M. to 2:00 P.M. Forty-four percent of the incoming collection vehicles were 11.4 to 15.2 cubic meters in volume, and twenty-five percent were 3.8 to 10.6 cubic meters. Thirty-eight percent of the incoming vehicles belonged to the St. Paul Department of Public Works; lesser percentages belonged to each of several private collectors.

2. Nine-kilogram daily composite samples of incoming waste were analyzed. Baler feed sample solid waste densities ranged from 39 to 103 kg/m^3, with a mean of 79.5 kg/m^3 and a standard deviation of 17.5 kg/m^3 (wet weight).

3. Average wet weight composition of baler feed waste samples in percent was: paper- 31, metal - 13, wood - 11, glass and ceramics - 9, garden - 8. Less than 7 percent composition each was observed for textiles, rubber and leather, food, rocks and dirt, and smalls and fines. Average dry weight moisture content of the solid waste samples and bale core samples, respectively, was 45.4 and 31.5 percent. Average dry weight organic content for the solid waste and bale samples, respectively, was 76.2 and 75.2 percent. The range of organic content of the solid waste samples was 60 to 89 percent, and bale samples 64 to 84 percent. The range of moisture content was 15 to 71, and 26 to 82 percent for incoming and baled solid waste, respectively.

4. Ten samples of both strained and unstrained liquid squeezed during baling showed the following ranges of constituents: pH - 3.2 to 4.9, total coliform - 1,200 to 24,000 MPN/100 ml, fecal coliform - 0 MPN/100 ml, BOD_5 - 0 to 3,940 mg/l, chloride - 965 to 2,620 mg/l, SO_4 - 3,800 to 4,400 mg/l, sulfide - 5 to 17 mg/l, TDS - 40,820 to 64,310 mg/l, NO_3 - 11.1 to 70.6 mg/l, NH_3 - 0 to 1,445 mg/l, and organic nitrogen - 730 to 2,817 mg/l.

C. Nature of Bales Produced.

1. Three methods of bale monitoring were employed: each bale was weighed by the control tower operator, each tenth bale was measured for volume and expansion, and three 5-cm core samples from two randomly chosen bales were taken daily.

2. Average bale production time for the tenth bale was 1.73 minutes, with a small standard deviation of 0.16, indicating a consistent production time.

3. Bales were observed to expand somewhat initially during the period ten minutes to one day after production, and then to contract somewhat between one day and one week after production. This latter settling phenomenon is attributable to evapotranspiration of bale moisture. At one hour after production, average bale expansion (in terms of volume) was 7.4 percent; at one day (and for one days' tenth bales three days elapsed over a weekend before measuring) after production, 28.4 percent; and at one week after production, 24.6 percent.

4. Ten minutes after production, average tenth bale height was 1.12 m, average width was 1.04 m, and average length was 1.35 m. Percent expansion at one hour, one day, and one week after production, respectively, was height - 2.5. 5.7, and 3.7; width - 1.4, 8.3, and 9.6; and length - 3.3, 13.0, and 10.8.

5. Average bale weight for all bales was 1,282 kg, with a standard deviation of 50 kg. Average daily densities ranged from 725 to 933 kg/cu m ten minutes after production; density was thus fairly non-uniform. Two of 66 tenth bales (3 percent) were observed to fall apart at the baling plant; these had large quantities of grass. At the landfill, 14 of 582 bales (2.4 percent) observed were damaged or broken.

6. The average number of bales produced per hour was 18.1 up to March 1974, and 22 thereafter. The average number per day was 256 and 341, respectively. The increase after March was due to change in personnel and an overhaul of the baling mechanism. The first and second labor shifts each worked an average of 8 hours per day.

D. Transport Net and Balefill Operations.

1. The transport network consisted of four enclosed cab tractors and five flat-bed trailers. Sixteen bales can be carried on each vehicle, but the usual load was 14 bales to comply with Minnesota State Highway vehicle load limits.

2. Transport vehicle rigging placement time averaged 6.69 man-minutes, with a standard deviation of 2.06. Transport vehicle tailgate installation time averaged 1.17 man-minutes, with a standard deviation of 0.51. One, two, or three men completed these tasks. This translates to 2.4 and 3.2 man-hours per day before and after March 1974, respectively, for the total rigging and tailgate installation procedure.

3. Bales were stacked three high and side-by-side at the landfill. The frequency of soil cover was observed to be at approximately weekly intervals, except that during winter periods when the ground was frozen no cover soil was applied.

4. The balefill scored 66 out of a possible 100 on an EPA landfill evaluation form. The lack of daily cover soil reduced rating by 20 points. Spaces between bales were generally greater along the long face than the short; site irregularities caused spaces in the fill. Surface water, broken bale, litter, dust, and non-fly vector problems were not significant. Fly emergence studies indicated baling alone without cover soil will not significantly reduce fly emergence.

E. Time Performance of Baling Plant and Transport Net.

1. Time studies of the baling process were made for 30 minutes twice daily. Daily video tape recordings of the gateman, loader operator, and control tower baler operator were made.

2. Measured percent machine idle times, including waiting time, were: loader - 30, conveyors - 49, scale - 38, baler - 20, pusher - 72, and transport trucks - 29.

3. Average process times for significant operations at the baling plant and balefill for the 137-second-cycle baler were observed to be (in min/bale): dumping solid waste - 2.40, loading conveyor - 1.50, conveying solid waste - 3.00, measuring charge - 0.05, baling (includes loading charge box) - 3.05, and loading trailer - 3.15. Other process times are recorded in minutes per truckload (an average of fifteen bales): waiting before travel - 21.0, transporting bales - 30.0, and waiting to be unloaded - 25.0. Average time from when collection trucks dumped solid waste to when loaded transport trucks left the plant was 48.85 minutes, excluding solid waste storage time between dumping and the beginning of the baling operation.

4. Percent idle times for the baling plant personnel were gateman - 55, loader operator - 25, transport drivers - 31, and sorters - 84.

5. Problems observed with baling plant machines were interference with the baler by the loader and conveyor, stopping of the conveyor while loading the scale, and an inoperative unloading platform requiring a special forklift to raise it while trailer beds were changed.

6. Coordination of work positions may be improved, as indicated by high idle time percentages, overloading of the gateman at times, and unclear assignment of records and maintenance responsibilities.

7. A way for employees to temporarily fill in for the gateman, loader operator, and control tower operator could improve bale production rate as much as 5 percent. Such redesigns of work responsibilities will increase productivity and minimize labor costs.

8. Improved operations in loading the conveyor may help to reduce delays and collision risks and keep a more constant amount of unbaled solid waste on the baling plant floor.

9. Under 90-second bale cycle conditions, as opposed to the current 137-second cycle, the conveyor loader and scale configuration will have to be modified or replaced. An overhead crane, a conveyor covering the total length of the plant, a gravity conveyor, and a mechanical mixer and loader are possible modifications.

10. Mechanical means of sorting solid waste may make recycling of materials such as paper, aluminum, steel, tin, and glass economically feasible. Separation of corrugated is presently accomplished by hand at a profit.

11. Ability, reliability, and accessibility for the baling system were determined over two time periods. Ability average 18.1 and 21.6 bales/hour, reliability figures were 6.38 and 6.78 (average 6.53) hours/8-hour day, and accessibility was 21.5 hours/day. Overall plant performance averaged 128 bales/8 hour shift before March 1974, with expected daily output of 256 bales.

12. To improve plant performance and lower costs, the following measures are suggested for large-scale baling operations: larger storage pits to store and mix the solid waste, better control of drainage at the baling plant, better ventilation at the plant, shielding of the baling equipment to prevent squirting of wet wastes, implementation of dust control at the baling plant, and a more systematic traffic pattern for collection vehicle arrivals.

F. Costs.

1. Total baling plant costs were $5.41 per bale, $4.17 per kkg, and $3.78 per ton during the first period and $6.95 per bale, $5.33 per kkg, and $4.83 per ton during the second monitoring period.

2. First-year transport net costs were $1.73 per bale, $1.33 per kkg, and $1.21 per ton; second period costs were $2.15 per bale, $1.65 per kkg, and $1.50 per ton.

3. Balefill costs ran $1.47 per bale, $1.13 per kkg, and $1.03 per ton during the first period and $1.34 per bale, $1.03 per kkg, and $0.93 per ton during the second period.

4. Total system costs were \$8.61 and \$10.44 per bale, \$6.63 and \$8.01 per kkg, and \$6.02 and \$7.26 per ton during the first year and second monitoring periods, respectively.

5. System maintenance costs remained at about 15 percent of the total through both periods.

6. Predicted total costs for a revised system using the 90-second-cycle baler and an overhead crane, at \$4.23 per kkg (\$3.82 per ton), were less than comparable milling costs of \$4.73 per kkg(\$4.30 per ton), or combined milling/baling costs of \$4.90 per kkg (\$4.47 per ton).

G. Test Cell Monitoring.

1. Sump leachate had an average pH of 6.7 and an initial BOD_5 of 25 mg/l. BOD_5 peaked about 312 days after test cell filling at 545 mg/l. Organic nitrogen levels fluctuated between about 10 and 20 mg/l. Chlorides and total dissolved solids showed level trends of about 379 and 1,982 mg/l, respectively. The bale test cell leachate was low in BOD_5, chlorides, and TDS, compared with values from other landfills. The total leachate quantity from the test cell measured 18,800 liters, and total precipitation onto the cell was 490,000 liters, over a 11-month period.

2. Leachate samples taken from lysimeters showed that BOD_5, total dissolved solids, and chlorides increased with an increase in depth, while pH remained relatively constant at all levels.

3. With the exception of an early sharp increase in bale temperatures (due to decomposition), trends in the baled solid waste followed fluctuations in ambient air temperatures.

4. Carbon dioxide gas concentrations reached a maximum of 30.5 percent by volume and methane 17.6 percent during the 14 months of monitoring. Oxygen ranged from zero to 18.2 percent by volume.

5. Carbon dioxide and methane levels increased with time at all depths, while oxygen dropped. These effects were more pronounced at the eight-foot depth. In all cases, hydrogen sulfide levels remained lower than 0.1 percent by volume.

6. Elevation changes were determined at five monitoring stations. The test cell bales expanded 13 percent during the first 10 days and remained stable over the following 12 months. The bottom bales expanded the least.

7. Auger sampling was performed once after about one year of field studies, on both the test cell and landfill. The temperature at the same depths decreased with the age of the fill material. Temperature in all boreholes increased with depth. The average organic content decreased, apparently with fill age from 54.5 to 38.4 percent between wastes placed two years apart. Moisture content ranged from 24.8 to 96.5 percent by weight, averaged 46.5 percent, and was independent of the age of the fill.

RECOMMENDATIONS

The following recommended improvements are based on a five-day on-site study of the St. Paul high-pressure baling plant.

A. Dumping Area

Random arrivals of full refuse trucks at the baling plant sometimes exceeded the gateman's ability to direct them for loading and do simultaneously the necessary paperwork for fee charging. This paperwork was done inside the plant building, but automatic measuring and billing equipment installed away from the unloading area would have expedited the unloading process and plant operations. Improved unloading and storage facilities (such as a larger storage hopper) would have improved materials handling.

Traffic in the dumping area created a safety hazard. Arriving trucks had to back in across the unloading floor, where other trucks and the loader were maneuvering. The resulting congestion and confusion impeded unloading and made for generally poor operating conditions. This could have been avoided by two changes in building layout. First, waste could be dumped into a pit where waste mixing, loading, and conveying could be readily handled in a separated area. This measure would have increased plant storage capacity, eliminated the potential for accidents between trucks and the loader, and also alleviated the need for an inside gateman. Second, a well-defined traffic-flow pattern, where all trucks travel in the same direction, would have reduced the accident potential among the trucks themselves.

B. Conveyor and Baler

It would have been advantageous to have eliminated the raised section of the conveyor. Then the loader could have filled any empty sections of the conveyor and, in case of a conveyor shutdown, loaded the scale platen directly. A variable speed control on the conveyor would also have been useful in efficiently regulating the speed at which full or empty sections of the conveyors were moved. Having a completely level conveyor would require that the baler be installed in an excavated area or that the refuse truck access be elevated above ground level. A combination would be best so that the bale transport trucks could gain access to the baler pushers to load bales from a shallow, below-grade access ramp. By allowing the scale platen to be loaded directly by the loader, the availability and reliability of the baling plant would increase since the conveyor experienced more downtime than the baler.

A pan to collect slurry and liquid squeezed from the baler should be designed and installed below the baling chamber, gathering ram and compacting ram. The pan would collect liquid that drips from these areas and also would intercept liquid that tended to squirt a considerable distance from the baling chamber. The liquid could be directed by gravity into a large mobile drum or an equivalent container that could be unloaded onto the solid waste storage pile for baling.

C. Alternative Baling Plant Equipment

Under 90-second bale cycle conditions, as opposed to the current 137-second cycle, the waste feed will have to be faster and more reliable. An overhead crane should be considered as an alternative to the skiploaders and possibly even the conveyor. If designed and installed properly, this alternative could significantly reduce construction and operating costs and might possibly improve the waste handling efficiency. The control room might be mounted above the conveyor, giving one operator responsibility for all solid waste handling inside the plant. This would require an improved automatic baler control system so that the operator could load the scale platen with a new solid waste charge while the baler was baling the previous charge.

A conveyor extending the entire length of the plant would allow more rapid loading from many positions. A gravity conveyor chute would reduce downtime associated with mechanical conveyors, but would have to be monitored for jamming. A diverging chute could minimize jam-ups.

A mechanical mixer and loader may be a possible configuration. The waste would be deposited in a pit with a mixer. The waste would be loaded directly from the mixer onto the baler scale, or by conveyor or chute.

D. Bale Transport

The tractor-trailers used to haul the bales to the landfill were equipped with custom-made, nylon mesh curtains. These curtains covered the bales during transport to keep litter from being blown off. It took about three minutes either to close or open the curtains. This time could have been reduced by improved curtain design or enclosed-body trailers with hinged sides to allow unloading of bales.

In locations where land disposal sites are over 50 to 100 miles from the baling plant (as determined by local economics), the use of railroad or barge transportation would be less costly.

E. Maintenance and Repair

Lists of recommended spare parts inventories for the baler and other plant equipment were available from equipment manufacturers. An inventory stock of the recommended parts could have reduced some of the time to complete parts replacement maintenance.

Also, the parts inventory list should be reviewed annually to determine which parts are replaced most frequently and the inventory adjusted accordingly. This will keep the inventory adjusted to the age of equipment and thus allow for maintaining the minimum inventory.

F. Labor

Mechanical equipment and automation could have reduced operating costs, although the scope for this in the baling operation was comparatively small since mechanical power did most of the work in the system. Labor was used largely for control, maintenance, and the salvage (metal and corrugated cardboard) operation. The recommendation on use of a crane to load the baler scale platen eliminates one employee.

Revision of work assignments to designate employees that would temporarily fill in for the gateman, loader operator, and control tower operator could improve the overall plant bale production rate as much as 5 percent. Such revised work responsibilities will reduce plant downtime due to labor break time and thus increase productivity.

G. Plant and Grounds Design

Adequate drainage and grading outside the plant would eliminate muddy roadways. Gravel or asphalt road surfacing with stormwater drainage are needed to eliminate bale truck and other vehicle wet weather access problems. Also, dry weather dust problems would be eliminated.

Improved forced air or induction ventilation at the roof of the baling plant would assist in removing odors and dust created by the solid waste. Particularly, if an inclined conveyor is used to feed waste into the baler, the elevated conveyor section where waste is dropped onto the scale platen creates the most dust and could be removed through roof vents. Cross ventilation through open doors at each end of the baling plant is also helpful.

Techniques to control dust, in addition to the aforementioned roof vents, are needed. Face masks with filters were provided to employees at the St. Paul plant. Possibly, dust control could be accomplished by small quantities of water sprayed onto the wastes. The amount of water required would have to be minimized to keep the moisture content below the 30 percent wet weight maximum for making structurally sound bales. Other problems of increased odor may develop if the waste is moistened. The aforementioned roof ventilation may reduce the impact of odors.

H. Resource Reclamation

Mechanical methods of segregating solid waste components such as corrugated cardboard, ferrous, aluminum and glass may make recycling economically feasible. Separation of corrugated was accomplished by hand at a profit. Without preprocessing, magnetic separation may be feasible for ferrous. Shredding and air classification would allow separation of the above-mentioned materials. The shredded waste may not produce good bales without binding.

I. Landfill

Daily placement of cover soil on the horizontal surface of the top bales in the bale landfill would make the operation more in compliance with a sanitary landfill. (Although daily cover was not feasible in St. Paul during the winter due to thick ground frost, it could have been placed daily at other times.)

Placing daily or other cover on the vertical working face is not feasible. Thus, a new definition and guidelines for a "sanitary" bale landfill should be developed as a guide to environmentally safe operation for bale landfills.

J. Recommendations for Further Study

The completed test cell and full-scale balefill should be monitored for a five-year period to establish longer term gas, temperature, leachate, settlement, and biodegradation data. The potential for groundwater pollution (from the leachate) and for other environmental impacts could be more accurately determined as a result of such additional data acquisition and analysis. Additional monitoring for balefill foundation characteristics should be performed to determine the potential suitability of balefilled land for supporting structures of various sizes.

Additional investigations at other sites and with different waste compositions are needed to extend available technical knowledge. The purpose of these additional investigations would be to determine the environmental impact of the St. Paul fill (for comparison with other balefills and with traditional landfills), to ascertain the potential of the completed site for various uses (including waiting time and special measures required), to begin to generalize for balefills as a category of land disposal alternatives, and to obtain sufficient information to develop guidelines for an environmentally acceptable bale landfill operation.

SECTION 1

INTRODUCTION

A. Objectives and Scope.

As authorized by Environmental Protection Agency Contract 68003-0332 (June, 1973, and extension August, 1974), a 19-month investigation of the operational, economic, and environmental aspects of baling solid waste, transporting bales, and disposal into a sanitary landfill was undertaken. This report presents the results of two phases of work under which the project was performed. Phase 1 consisted of an intensive five-day field study of the baling plant and transport network under normal operating conditions, as well as a review of historical cost and operating information. Technical planning for the field-test work program involved three months of professional preparation. The purpose of this first phase of the study was to define baling plant operation to determine the parameters affecting the production rate and quality of the bales. The objectives designed to fulfill this phase were to describe the following:

1. The physical plant, including facilities layout, and stationary and mobile equipment.

2. The plant operation, including equipment reliability, maintenance requirements, and use of labor.

3. The nature of the incoming solid waste, including the rate of inflow and the physical characteristics of the solid waste.

4. The baling operation, including rate, method and an analysis of the bales and the liquid squeezed from the solid waste during baling.

5. The activities associated with the baling plant, i.e., the transport network and the landfill.

6. The environmental impact of the baling system.

7. The costs associated with construction, maintenance, and operation.

Phase 2 of the study included organizing the results of specific monitoring activities, both at the landfill and at the test cell, where conditions were evaluated under more controlled circumstances. In the test cell, gas generation, temperature, settlement, leachate qualities, moisture content, and organic content were measured. Auger drilling was conducted in the test cell and landfill areas on one day to assess biodegradation conditions.

B. Approach.

The baling plant was located in St. Paul, Minnesota, and operated by American Systems, Incorporated, a division of American Hoist and Derrick Company. The Phase I monitoring of the plant described in this report took place September 20 through 26, 1973. In order to evaluate the baling operation on each of these days, the daily monitoring work task schedule, shown in Figure 1-1, was developed. Task numbers one, ten, and eleven were performed by a Ralph Stone and Company, Inc., staff member with the cooperation of the baling plant forklift operator, an employee of American Systems, Incorporated. The forklift operator removed each tenth bale from the plant discharge platform, transported it to the temporary storage area designed for the bale measuring, and finally placed the segregated tenth bales on a separate truck for transportation to the balefill. Another American Systems, Incorporated, employee then drove this truck to the landfill at the end of the first shift each day. The bale fill operator unloaded the truck and placed the special bales in the test cell area. A crew of three Ralph Stone and Company, Incorporated, staff performed tasks two, three and eight (see Figure 1-1). They were assisted by the loader operator, an employee of American Systems, Incorporated, staff engineers in cooperation with American Hoist and Derrick Company balefill staff.

Data forms used during the five-day monitoring period are included in Appendix A. The data resulting from the five-day monitoring program provided the information necessary to accomplish objectives two, three, and four: descriptions of the plant operation, the incoming waste and the baling process. The information necessary for objectives one and five, descriptions of the baling plant, the transport network and the balefill, respectively, were either provided by American Hoist and Derrick Company personnel or obtained through the efforts of Ralph Stone and Company, Incorporated, engineers prior to the five-day monitoring period. Environmental impact and cost analyses, objectives six and seven, respectively, were based on data obtained during the five-day monitoring program and guided by comparison with other solid waste disposal operations.

Phase 2, test cell and landfill monitoring, was set up between August 2, 1973 and October 5, 1973, with baseline monitoring beginning on September 27, 1973. The test cell measurements were taken through the end of November, 1974. Section 10 of this report thoroughly details the results of test cell monitoring. The bale landfill monitoring ended June 26, 1974, the last monitoring day during which the landfill was being covered with soil prior to ending all solid waste baling operations on June 29, 1974. The baling plant was sold and operations ceased in June, 1974.

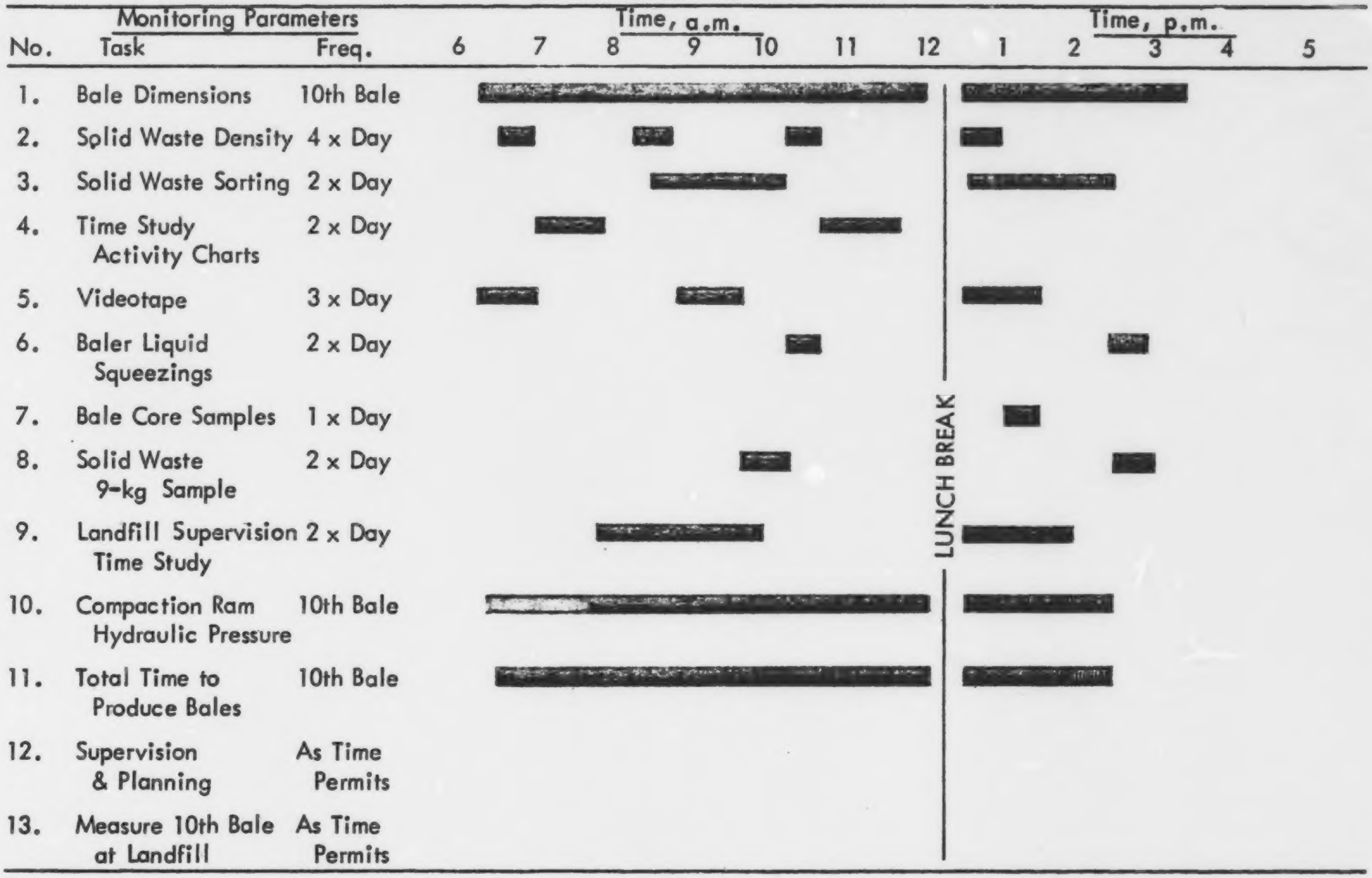


FIGURE 1-1

BALING PLANT MONITORING TASK SCHEDULE

SECTION 2
GENERAL AREA AND OPERATIONS DESCRIPTION

A. City of St. Paul.

The baling plant served the City of St. Paul, a part of the Minneapolis/St. Paul Standard Metropolitan Statistical Area. This area is located in the southeast part of Minnesota and includes the Counties of Anoka, Dakota, Hennepin, Ramsey, and Washington. The Minneapolis-St. Paul SMSA covers 5,457 square kilometers (2,107 square miles) and has a population of 1,813,647 (1970 census).

B. Baling Plant General Location and Access.

The American Systems, Incorporated, baling plant lay two city blocks south of the Mississippi River (Figure 2-1). It was directly across the river from downtown St. Paul. South Robert Street was the nearest arterial roadway, running north-south and crossing the Mississippi River at the Robert Street Bridge. The baling plant lay approximately 180 meters (200 yards) west of South Robert Street. Plato Boulevard, a smaller east-west roadway, provided access to the plant from South Robert Street or from Wabasha Street, the north-south roadway to the west. Starkey Street, a dead-end street that extends south from Plato Boulevard, provided access to the plant (see Figure 2-2).

The baling plant was located in a commercial-industrial zoned area. The traffic to and from the baling plant was composed of solid waste collection trucks and baling plant-related vehicles, as well as commercial-industrial vehicles. The nearest residential area lay approximately 90 meters (100 yards) south of the site, across Wood Street. However, Wood Street is at the top of a rise, approximately 10 meters higher than the adjacent land, making the plant invisible from the residences.

Noise, dust and odor resulting from the baling operations were largely contained within the plant structure. As shown in Photograph 2-2 (b), from the outside the plant appeared to be a typical prefabricated light industrial plant. The only outdoor storage was a neatly stacked pile of wooden pallets located west of the building. The transport vehicles were parked near the southeast corner of the lot. The asphalt-paved yards greatly minimized the dust raised by the vehicles. All roadways were asphalt-paved, including the southern side of the structure where the bale loading dock was located. Figure 2-3 shows the site layout. Except for a few flies transported with the collected unbaled refuse, no vectors were observed at the baling plant site.

C. Baling Plant Site.

1. Physical. The baling plant building was an Inland-Ryerson prefabricated 400-D metal building, 73 meters (240 feet) long and 37 meters (120 feet) wide. The eastern 24 meters (80 feet) of the plant have 10-meter (32-foot) high sides. The gabled roof rises at a 4/12 slope to reach a central crown 16 meters (52 feet) above the base of the building. The remaining sidewalls of the building are 7 meters (24 feet) high and the crown of the roof is 13 meters (44 feet) high. This split-level design provided additional

Scale:
1 cm = 0.44 km
(1" = 0.7 miles)

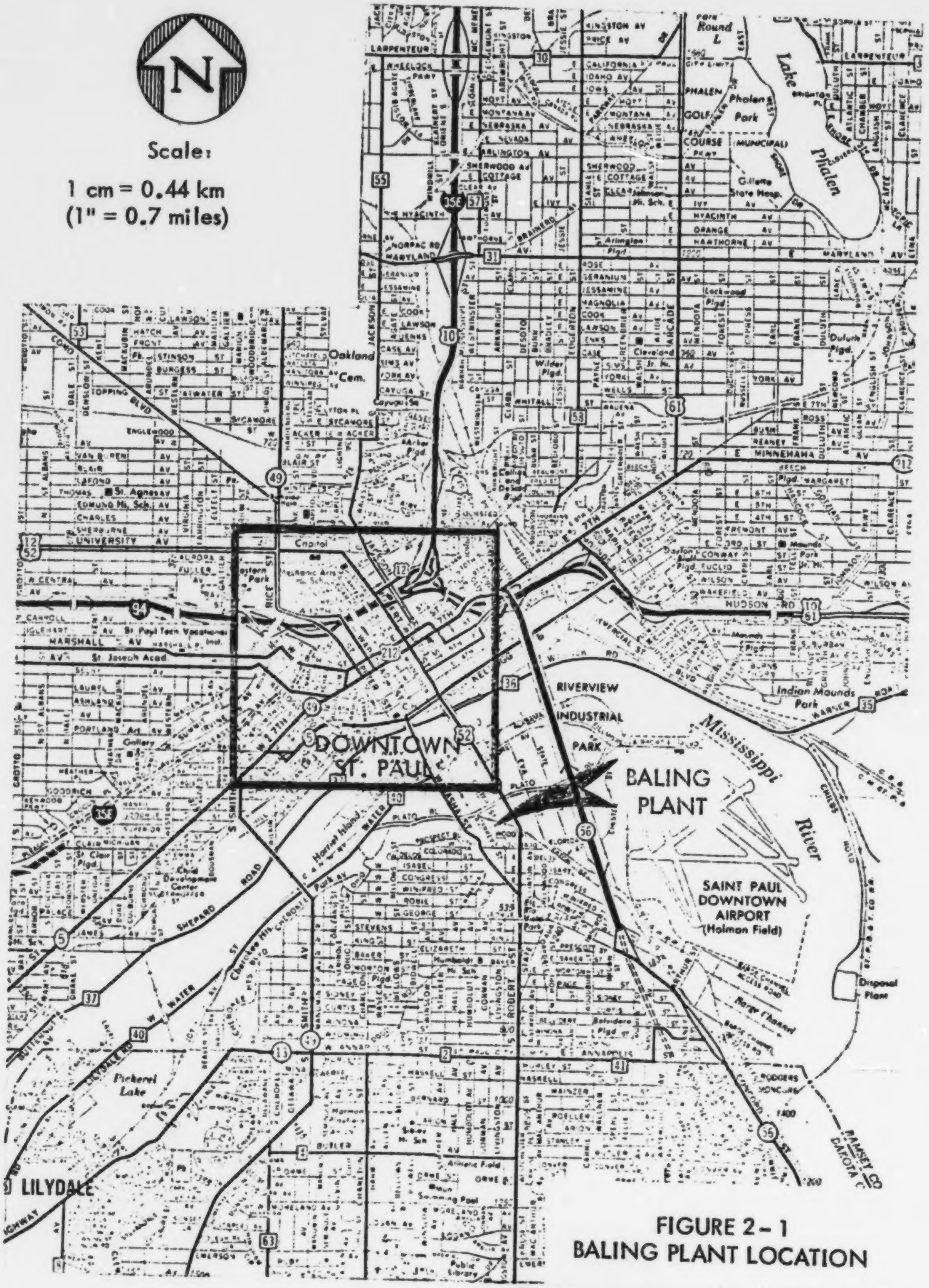

N
DOWNTOWN ST. PAUL
BALING PLANT
RIVERVIEW INDUSTRIAL PARK
SAINT PAUL DOWNTOWN AIRPORT (Holman Field)
Mississippi River
Lake Phalen
Phalen Park
Oakland Cem.
Indian Mounds Park
Disposal Plant
Pickerel Lake
LILYDALE
Capitol
UNIVERSITY AV
MARYLAND
LARPENTEUR
MINNEHAHA AV
HUDSON RD
SHEPARD ROAD
Harriet Island
94
35E
10
61
12
52
56
5
49

FIGURE 2-1
BALING PLANT LOCATION

Reproduced from best available copy.

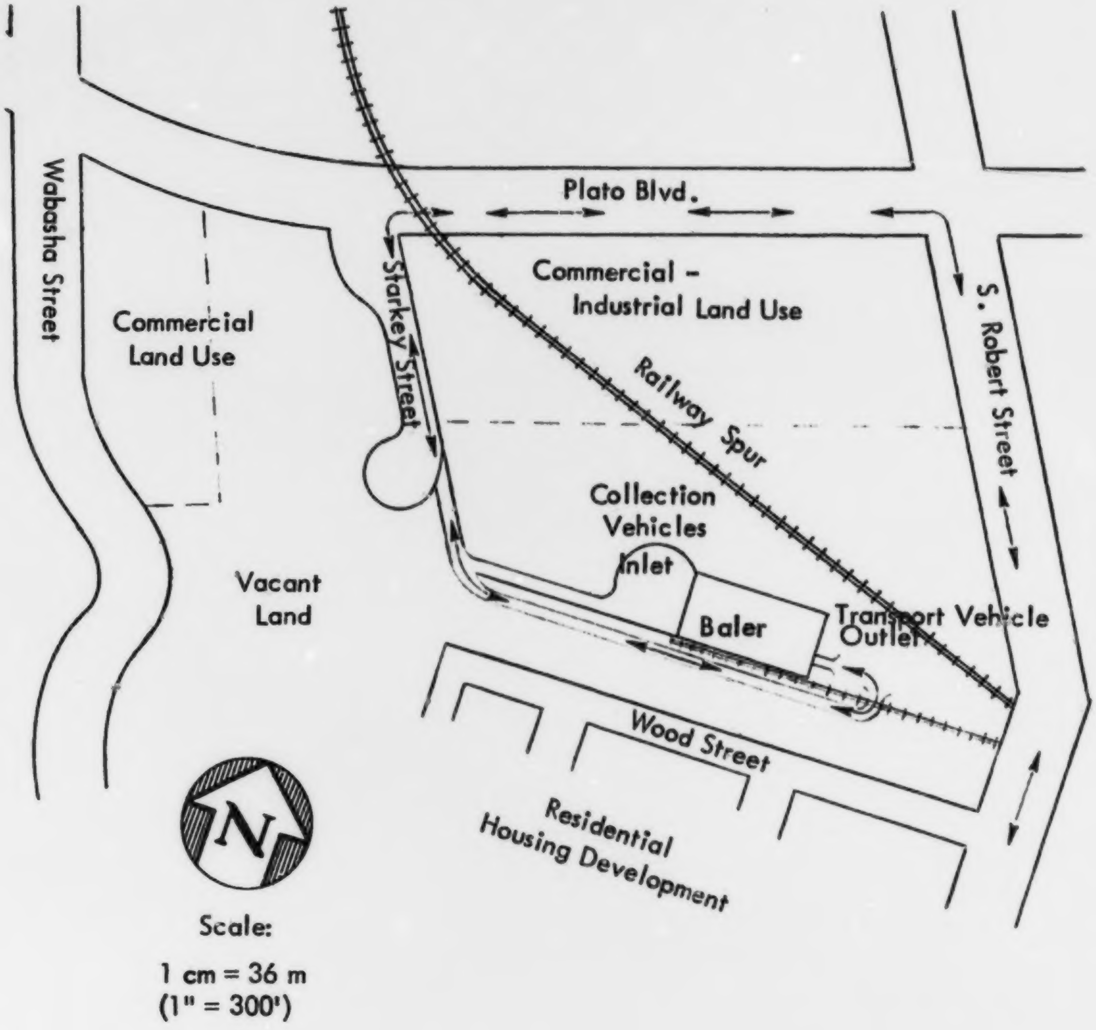

Plato Blvd.
Wabasha Street
Commercial Land Use
Starkey Street
Commercial - Industrial Land Use
S. Robert Street
Railway Spur
Collection Vehicles Inlet
Vacant Land
Baler
Transport Vehicle Outlet
Wood Street
Residential Housing Development
N
Scale:
1 cm = 36 m
(1" = 300')

FIGURE 2-2
BALING PLANT VICINITY
MAP WITH TRANSPORT FLOW

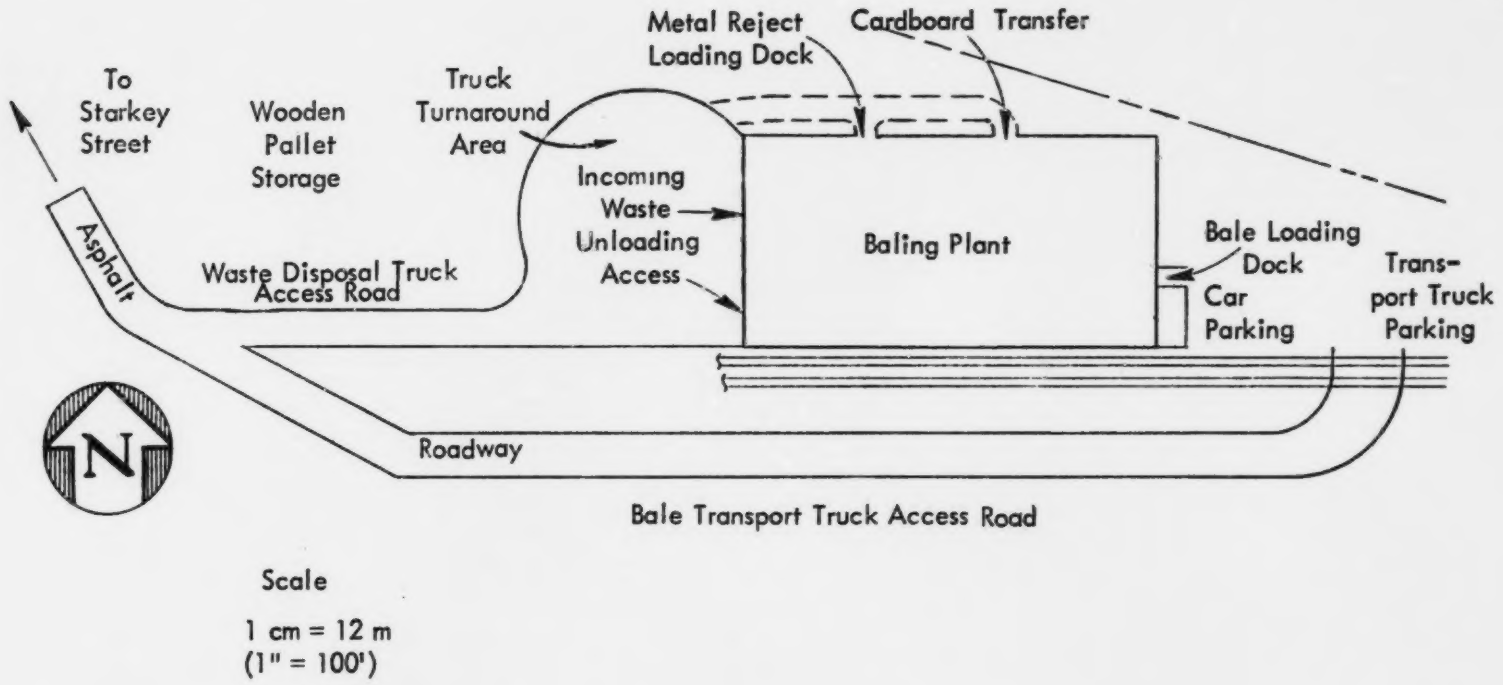

Metal Reject
Loading Dock
Cardboard Transfer
To
Starkey
Street
Wooden
Pallet
Storage
Truck
Turnaround
Area
Incoming
Waste
Unloading
Access
Baling Plant
Bale Loading
Dock
Car
Parking
Trans-
port Truck
Parking
Asphalt
Waste Disposal Truck
Access Road
N
Roadway
Bale Transport Truck Access Road
Scale
1 cm = 12 m
(1" = 100')

FIGURE 2-3
BALING PLANT SITE LAYOUT

height in the east section where the baler is located (see Figure 2-4).

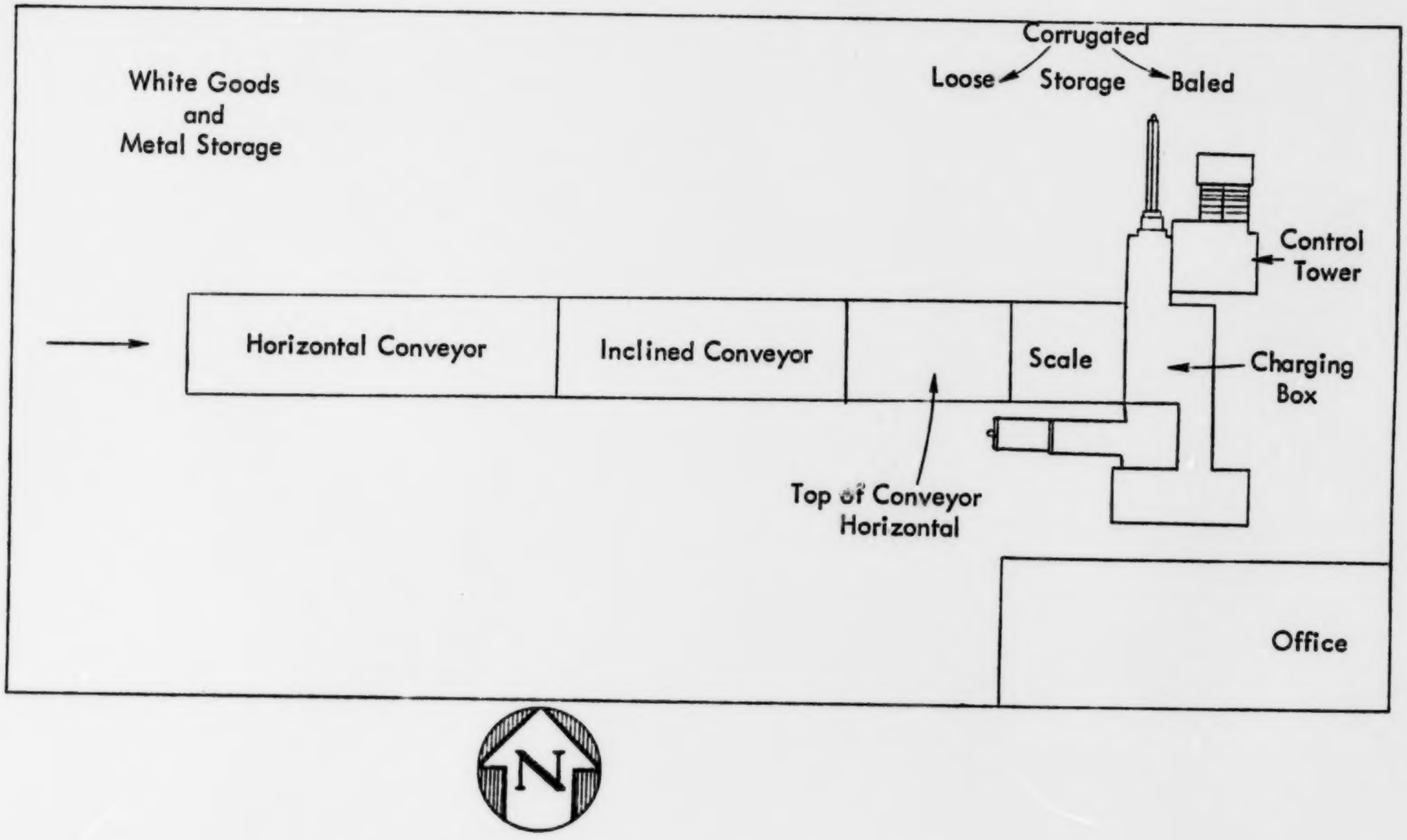
The plant appurtenances, such as in-wall partitions, loading dock, conveyor pit, etc., were constructed of concrete and/or 15-centimeter (6-inch) lightweight concrete blocks with a 10-centimeter (4-inch) thick Spancrete roof. The building was serviced by telephone, water, gas, sewer and electric utilities. The inner wall partitions were 3 meters (10 feet) high. The service area in the southeast corner also had concrete block walls and a 15 centimeter (6-inch) thick Spancrete roof. This area contained the toilet, parts storeroom, a lunch room, office, and mechanical (power) room which housed the baler electrical, oil pump and other equipment. The gate attendant's room was a portable wood structure about 1.0 m by 1.0 m by 2.4 m high. It contained a small table and a cash register. The control tower housed the control panel, the scale readout dial, and the operatot responsible for running the baler and conveyor. Details of these structures can be found in Appendix D.

2. Operation. The labor force at the baling plant during the one-week monitoring consisted of a gate attendant, a front-end loader operator, a utility (forklift) man, a maintenance man, two segregators, the control tower baler machine operator and the plant foreman. The control tower operator was designated a working leadman. The bale plant superintendent was also responsible for operating the landfill and the transport transfer trucks. Although he spent most of his time at his office in the baling plant, he technically was not part of the direct baling plant production staff.

The mobile equipment used at the baling plant consisted of a front-end loader, a forklift, a small "bobcat" type loader, and a hand-pushed electric floor sweeper which was on loan. Descriptions of baling plant machines can be found in Appendix C.

The baling plant functions constituted a process; the input to the process consisted of local municipal type solid waste and the output was the high density bales. The plant was designed on a linear basis; the input entered the plant at the west end, was transported through the plant, and the output exited at the east and ready for transport (Figures 2-5 and 2-6). A simple, direct way to describe the plant is to follow one cycle in the process.

Vehicles bearing incoming solid waste proceeded southward on Starkey Street and entered the site via the driveway at the end of Starkey Street. They then proceeded along the driveway to the eastern entrance yard. Here they were directed by the gate attendant from his position near one of the four eastern doors. The gate attendant's first function was to direct the driver of the vehicle to enter the plant through a designated door. The driver of the vehicle then used the yard to turn around and proceeded to back in through the designated door. Following the directions of the gate attendant, the driver continued backing the collection truck until he reached the desired dumping area. He then stopped and dumped his waste load onto the dumping floor. The gate attendant observed the load dumping to identify solid waste composition and note other special billing items and material requiring careful handling. (A copy of the fee schedule is shown in Photograph 2-1a.) During the unloading process the gate attendant filled out a vehicular fee ticket. (See Appendix B for data form.)


White Goods
and
Metal Storage
Corrugated
Loose
Storage
Baled
Control
Tower
Horizontal Conveyor
Inclined Conveyor
Scale
Charging
Box
Top of Conveyor
Horizontal
Office
N

No Scale

FIGURE 2-4
BALING PLANT
FLOOR PLAN

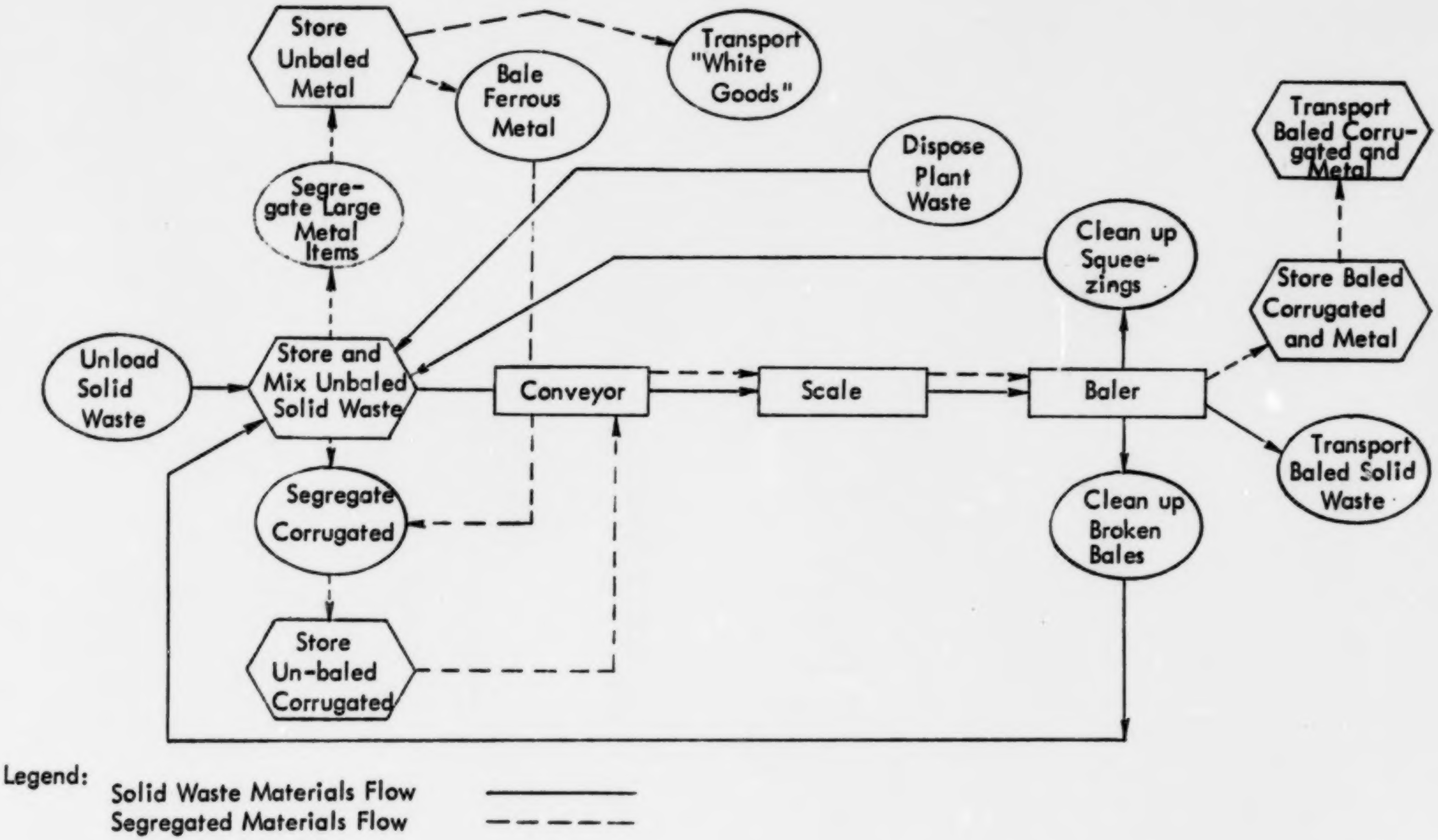

Store Unbaled Metal
Transport "White Goods"
Bale Ferrous Metal
Segregate Large Metal Items
Dispose Plant Waste
Transport Baled Corrugated and Metal
Clean up Squeezings
Store Baled Corrugated and Metal
Unload Solid Waste
Store and Mix Unbaled Solid Waste
Conveyor
Scale
Baler
Transport Baled Solid Waste
Segregate Corrugated
Clean up Broken Bales
Store Un-baled Corrugated
Legend:
Solid Waste Materials Flow
Segregated Materials Flow

FIGURE 2-5
BALING PLANT
MATERIALS FLOW SCHEMATIC

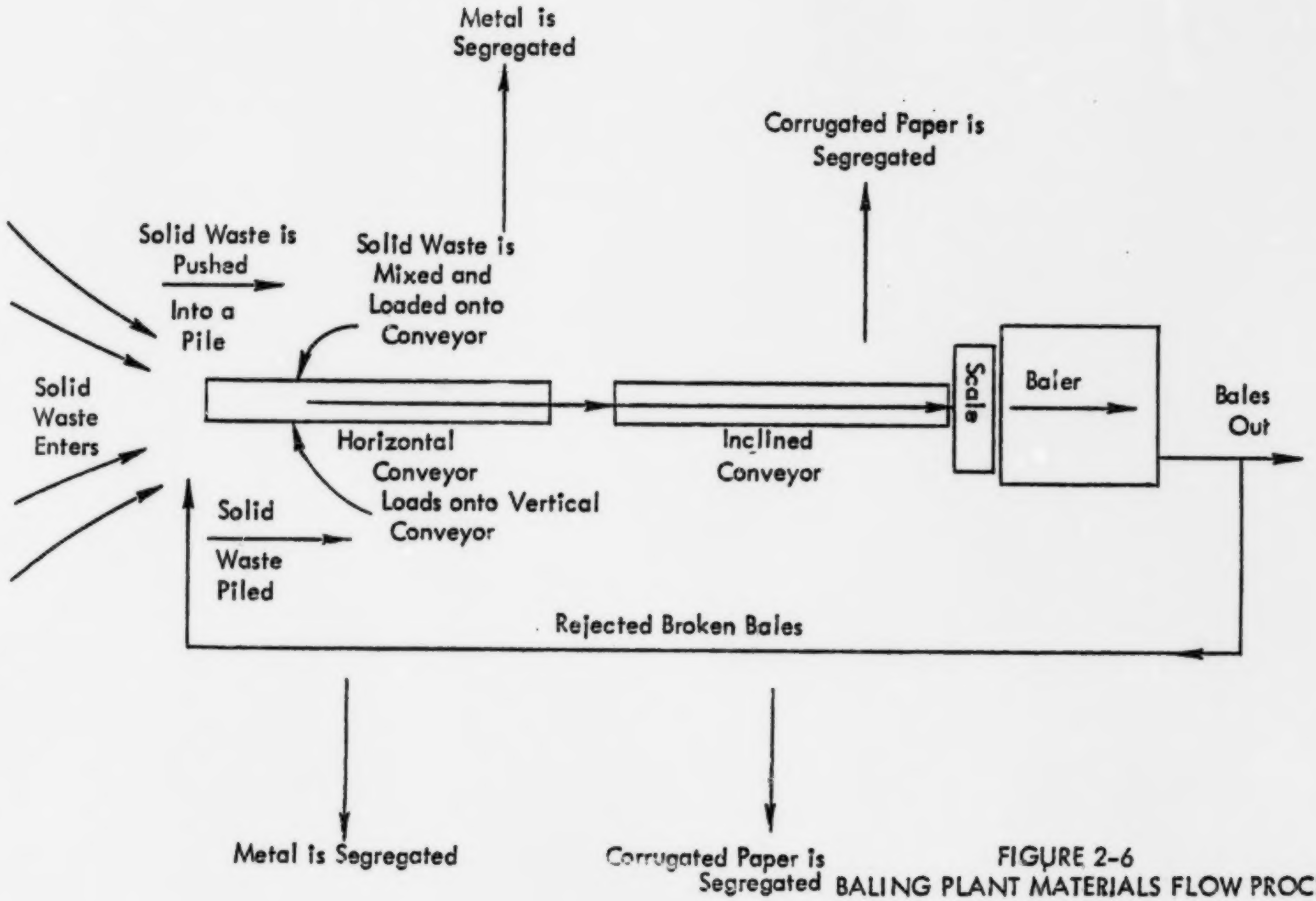

Metal is Segregated
Corrugated Paper is Segregated
Solid Waste is Pushed Into a Pile
Solid Waste is Mixed and Loaded onto Conveyor
Solid Waste Enters
Horizontal Conveyor Loads onto Vertical Conveyor
Solid Waste Piled
Inclined Conveyor
Scale
Baler
Bales Out
Rejected Broken Bales
Metal is Segregated
Corrugated Paper is Segregated

FIGURE 2-6
BALING PLANT MATERIALS FLOW PROCESS

Prior to vehicle departure he approached the collection vehicle driver and collected the fee. If the owner of the vehicle had a charge account with American Systems, Incorporated, the driver needed only sign the ticket; the vehicle was then free to leave. If no account existed the gateman collected the necessary fee. In this case the gate attendant returned to the gate attendant's room. In the room he used the cash register to ring up the fee on the ticket, deposit the money in the cash register and make change, if necessary. He then returned to the vehicle to give the driver the receipt and any change. The collection vehicle was then free to leave.

As soon as possible following empty vehicle departure, the loader operator drove the loader to the unloading area used by the vehicle and pushed the unloaded solid waste toward the east end of the building into a pile with other previously received solid waste. This kept the unloading areas open so that incoming waste collection vehicles could unload at all times. When the loader was not moving waste in the unloading areas, it loaded solid waste onto the horizontal pit conveyor. Incoming solid waste was unloaded on both sides of the conveyor by periodically directing trucks to each side. The solid waste was loaded alternately onto the conveyor from both sides so that the unloading area remains clear. The loader was used to mix the solid waste, keep the unloading floor clean, to sort out large metal objects white goods such as water heaters, stoves, etc., and also to segregate large corrugated items. The loader operator used the loader to mix the solid waste by turning the pile of waste in a rolling motion with the bucket. This was accomplished by inserting the bucket near the bottom of the pile and raising it until the material taken from the pile bottom was pushed onto the top of the pile. The loader operator used the loader to keep the work area neat by placing the bottom of the bucket on the ground and scraping it along the floor using a broom-like motion. He used the loader to sort out white goods by employing the bucket to back-drag the metal objects away from the pile. The loader bucket was then swept like a broom once again to push the item over to the north wall metal storage area. These rejected items were stored in a pile near the north wall. They were removed from the bale plant on a van truck when a full load accumulated, and either taken to a nearby scrap yard or alternately baled into Number 2 steel scrap and then sold.

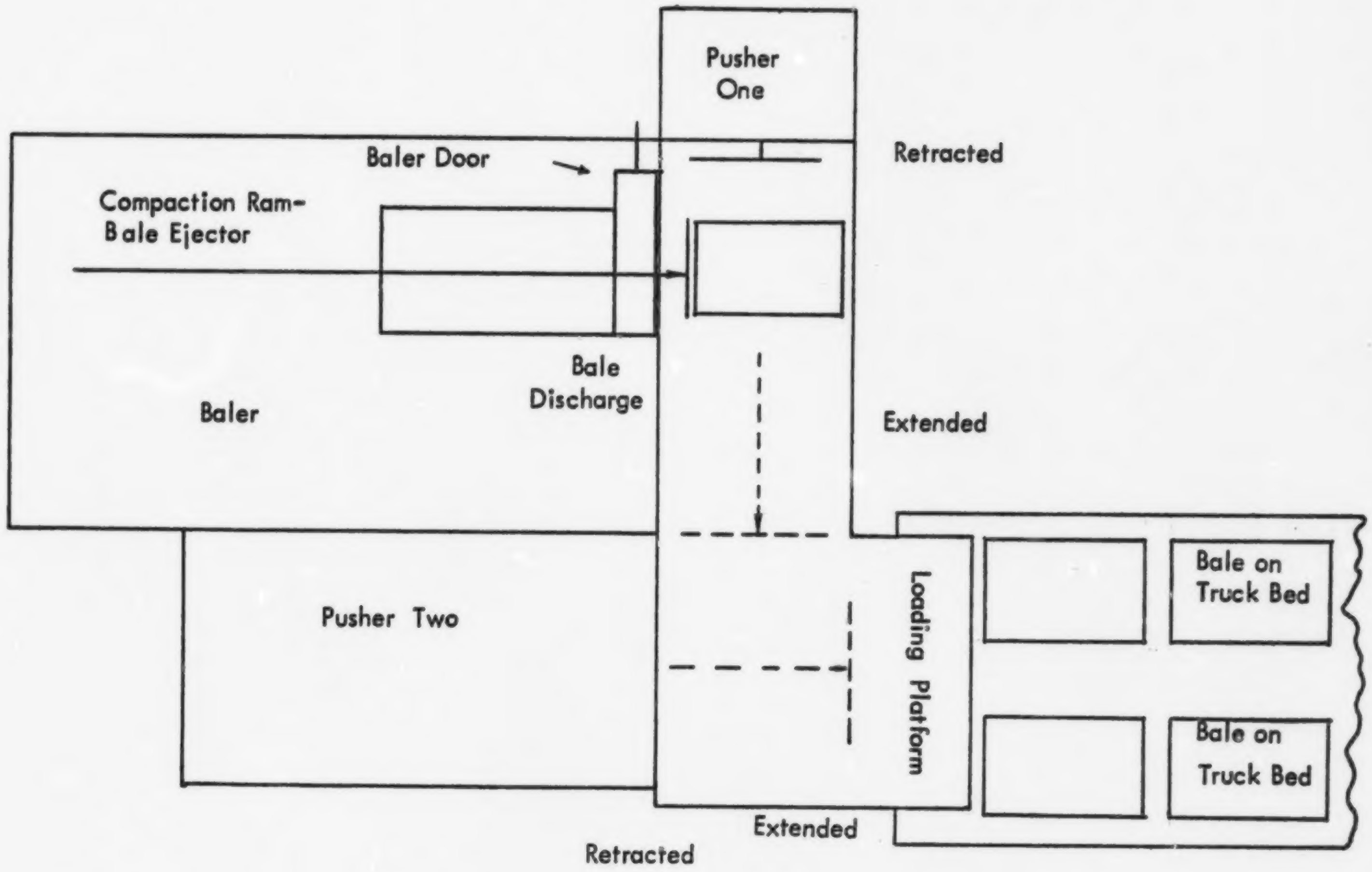
The horizontal 2-bar slat conveyor moved the solid waste along the pit and dumped it onto the bottom of the inclined conveyor. The inclined 2-bar slat conveyor then carried the waste upwards and discharged solid waste onto the scale platform. Just prior to the upper end of the conveyor there were platforms on both sides of the conveyor which were utilized by the two men that were corrugated segregators. These two men were equipped with hook poles to reach past the middle of the conveyor. They removed all corrugated that was in good condition and placed it on chutes behind them which were sloped down and away from the conveyor. The chutes directed the corrugated into piles on the plant floor which were periodically pushed into storage areas along the side walls. Corrugated moving was completed by the forklift operator, using the small "bobcat" loader. The area near the side door on the north wall was used for corrugated storage; incoming vehicles whose load consisted primarily of corrugated entered through the side door and dumped near the corrugated storage area. The corrugated was also baled in a separate run and sold to the secondary material dealer providing the highest bid.

The baler operator controlled the conveyor, scale, and baler equipment operation. When the weight of the waste material on the scales reached the desired amount (990 kg for normal solid waste), the baler operator stopped the conveyor. The subsequent events could then occur automatically or be controlled manually by the baler operator; in either case, the sequence of events was the same. The next step was the activation of the platen, a metal plate that pushed the waste across the scale and into the baler charging box. It could not be activated until the baler charging box lid opened. The charging box lid had to remain closed while the baler was producing a bale. A short delay routinely occurred between the stopping of the conveyor when the desired waste weight was reached and the activation of the platen to load the charging box. Once the lid closed, the baling process began.

The baler was basically composed of three hydraulic rams and a baling chamber which had three fixed walls, and a sliding door which acted as a fourth wall. The gatherer ram activated first and pushed the waste from the hopper into the baling chamber. The gatherer ram remained extended during the operation of the other two rams. The vertical ram, called a tramper, activated next. It pushed the charge down into the chamber and provided a ceiling (fifth wall) for the baling chamber. The final operation was the activation of the third ram, the compactor. The compactor became the final chamber wall, creating a box-like area into which the waste was compressed to about a 91.4 cm (36 in) by 91.4 cm by variable length (average = 122 cm or 48.0 in) bale. The wall on the eastern end of the baling chamber was the baler discharge door. After the bale was produced, the baler door opened. The compactor ram, which was still extended, was further extended to eject the bale out of the baling chamber onto a platform.

Two hydraulic pushers moved the bales into loading position (Figure 2-7). Pusher One, located adjacent to the baler door, pushed the ejected bale southward across a platform and extended just short of the path of Pusher Two, which was perpendicular to Pusher One. Thus, one discharged bale rested in front of Pusher Two after Pusher One retracted. However, Pusher Two had enough room in front for two bales. It, therefore, was activated only on every second cycle. Pusher One moved a second bale adjacent to the first and then pushed both bales into position in front of Pusher Two. When Pusher One retracted, Pusher Two was activated to push the two side-by-side bales onto a flat-bed truck. Two cycles later, Pusher Two was again activated. This time, the two bales pushed would, in turn, push the previous two bales along the truck bed. Each time two bales were pushed onto the vehicle, they pushed all of the bales ahead of them further along the truck bed. Loading continued until 14 or 16 bales occupied the truck, at which point Minnesota State Highway Department legal load limits were reached.

Operation of Pusher Two (see Figure 2-7) was the last operation part of the baling plant process. It was also the last operation which was controlled by the baler control panel. As was mentioned, the baler operator might, if desired, manually control all of the steps from the stopping of the conveyor through the operation of Pusher Two. He was also the working leadman. The height of the control tower allowed him to view the entire


Pusher One
Retracted
Baler Door
Compaction Ram-Bale Ejector
Bale Discharge
Baler
Extended
Pusher Two
Loading Platform
Bale on Truck Bed
Bale on Truck Bed
Extended
Retracted

No Scale

FIGURE 2-7
BALING PLANT HYDRAULIC PUSHERS

operation, and through the use of a public address system with a microphone in the control tower, he could communicate with other workers on the plant floor. He was responsible for assuring that the entire process ran smoothly.

The utility man has been mentioned only in connection with the operation of the small loader to move segregated corrugated, but his major responsibility was operating the forklift. He used the forklift whenever it was necessary to remove a bale from the bale discharge platform. This became necessary to remove occasional broken bales from the platform and deposit them onto the incoming solid waste pile for re-baling. Any portions which broke off of bales were swept up, placed in a wheelbarrow, and returned to the incoming waste stream for rebaling. If enough of the bale remained intact, it was loaded directly onto the transport vehicle using the forklift. Another major use of the forklift was to lift up the edge of the loading platform so that the bed of the transport vehicle could fit under the edge of the loading platform. This corrected the loading platform deflection caused by the weight of the bales. The lifting required was usually 2.5 to 5 cm (1-2 in.). When the forklift operator was not busy with the forklift or the small loader, he was responsible for other duties. He used the automated sweeper (when it was loaned to the plant) to keep the floors swept and helped the vehicle transport drivers perform the rigging operation. This operation was technically a part of the transport network, so it will be discussed in a later section.

A maintenance man was responsible for keeping the baling plant equipment in operating condition. He repaired minor equipment breakdowns which did not require extensive parts replacement. He could also fill in for the loader operator, the gateman, or the forklift operator in case of illness or injury. If not busy, he also assisted in transport-vehicles rigging and floor sweeping. There were two occupational trainees who work part-time at the baler plant. They were strictly used as cleanup men. The maintenance man spent some time supervising the work of these two employees.

The duties of the foreman were administrative; he was also responsible for repairing major breakdowns that occurred which did not involve obtaining parts or services not available at the baler plant.

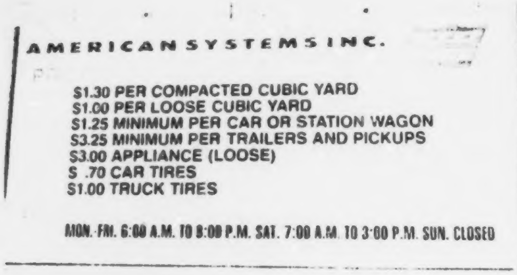
In addition to all of the above activities, one hour of each day was devoted to plant clean-up. All employees, excluding the foreman and the gate attendant, cleaned up the conveyor pit and the area below the baler. The waste they cleaned out of these areas was added to the incoming waste pile and subsequently baled. During the week of monitoring, cleanup was completed by both work shifts on different days. The first shift operated from 6:00 a.m. until 2:30 p.m. with one half-hour for lunch from 12:00p.m. to 12:30 p.m. A second shift started work at 2:30 p.m. and worked eight hours.

The above work description applied to the normal plant operation through September 17, 1973. The bale plant fees were scheduled to be increased on September 17, and many private solid waste collectors hauled their waste to an alternative private landfill location to avoid paying the higher fee. Institution of the fee increase had been initially delayed by the President's Cost of Living Council economic regulations. The diversion of the private solid waste collectors to the alternative private landfill disposal site reduced the number of hours worked at the plant during the second shift. The second shift hours varied from 4 to 8 per day during the week of monitoring, depending on the amount of solid waste received.

3. Qualitative Observations. The interior of the baling plant was described as musty. During dry periods the air was dusty, and during warm weather natural ventilation was provided at both ends of the plant through the open doors. During rainfall periods when solid waste was wet, there was little to no dust, but the solid waste characteristic odor increased. Some workers wore face masks provided by the Company, which covered the mouth and nose to cut down on the inhalation of dust particles. The plant was not well lighted, and much darker than normal daylight illumination. The plant interior was noisy due to the large empty building volume acting as a sound chamber. On the west end of the plant, noise sources were the loader and the unloading waste collection trucks. The east end of the plant was less noisy at floor level due to the conveyor-scale-charging box lid operations, which were the major noise sources; these were elevated high above floor level.

Plant operation aspects are shown in Photographs 2-1 through 2-4. Solid waste residues were ejected from the baler at several points, but the majority of the squeezings were extruded when the bale door opened. Small particles of solid waste, primarily grass and wood, were also squeezed out from the baling chamber past the gatherer and compaction rams. The vertical tramper ram tower walkway and ram framework had similar minor deposits of dry, crushed solid waste particles. A pile of this residue was observed blocking one side of the uppermost railing surrounding the tramper ram tower. At certain times during the high pressure compression, some liquid wastes squirted out of the baler and were sprayed up to 4.6 meters (15 feet) onto the control tower concrete supports One section of the service room wall opposite Pusher Two was also occasionally sprayed with liquid, leaving a permanent stain. The liquid spray quantities were minor, but proper shielding and drainage would have eliminated this phenomenon.

The activities occurring at the plant normally followed a moderately active pace. When several waste collection vehicles arrived simultaneously, the unloading area became jammed due to lack of a coordinated traffic flow plan. Cleanup was an ongoing effort involving the movement of wheelbarrows, shovels, brooms, and men. Corrugated usually cascaded down from the laborers positioned at the top of the conveyor. Personnel on the plant floor had to be alert to avoid walking under the falling corrugated. The corrugated fall area was roped off to keep people from walking in the area where the corrugated was falling to the floor. Often when a waste collection vehicle unloaded mostly corrugated, the hand separation of the salvageable material from unreusable waste took place directly on the baling plant floor. Minor plant maintenance operations took place at any time, involving transport vehicles, the baler, the forklift, or other equipment.



AMERICAN SYSTEMS INC.

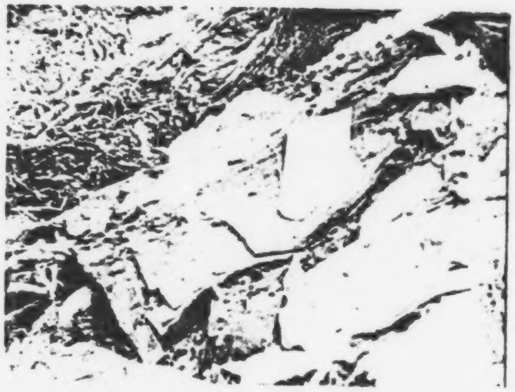
$1.30 PER COMPACTED CUBIC YARD
$1.00 PER LOOSE CUBIC YARD
$1.25 MINIMUM PER CAR OR STATION WAGON
$3.25 MINIMUM PER TRAILERS AND PICKUPS
$3.00 APPLIANCE (LOOSE)
$ .70 CAR TIRES
$1.00 TRUCK TIRES

MON.-FRI. 6:00 A.M. TO 8:00 P.M. SAT. 7:00 A.M. TO 3:00 P.M. SUN. CLOSED

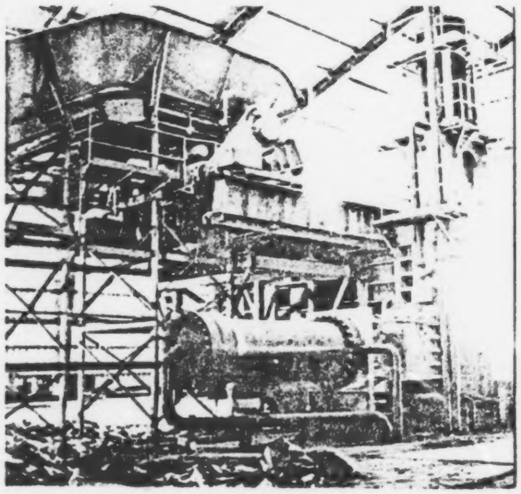
a. Prices for facility use

b. Bale plant bale truck loading area

c. Segregation of cardboard



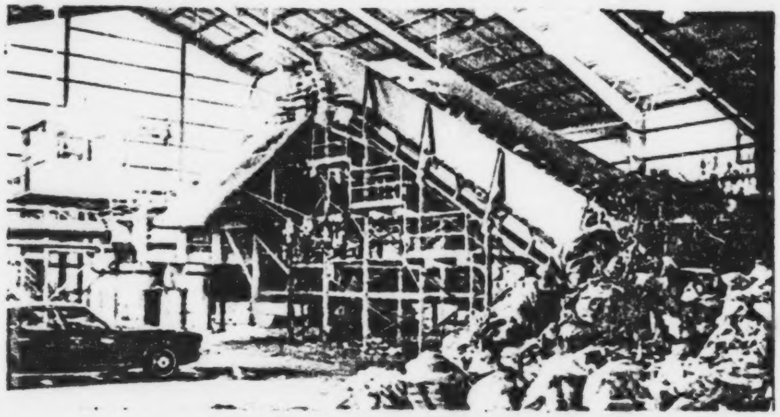
d. Refuse to be baled



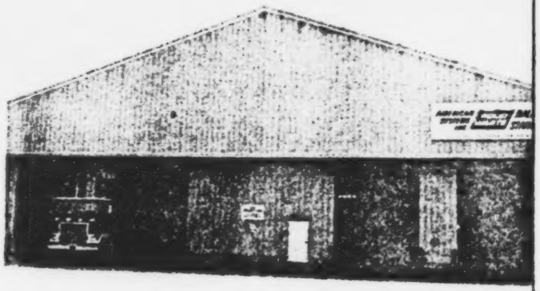
e. Baler – view of compaction ram

f. Baler control room

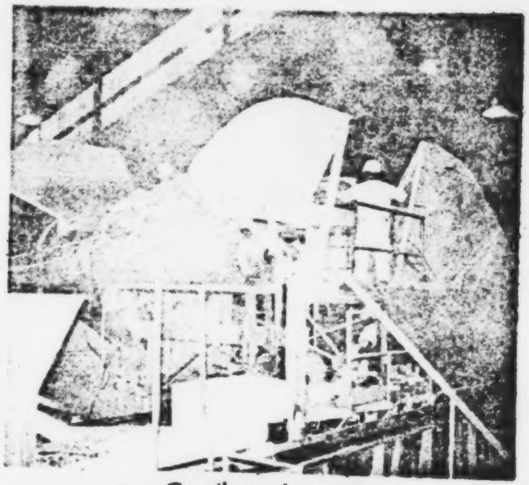
PHOTOGRAPH 2-1
BALING PLANT OPERATIONS (I)



a. Conveyor and control tower



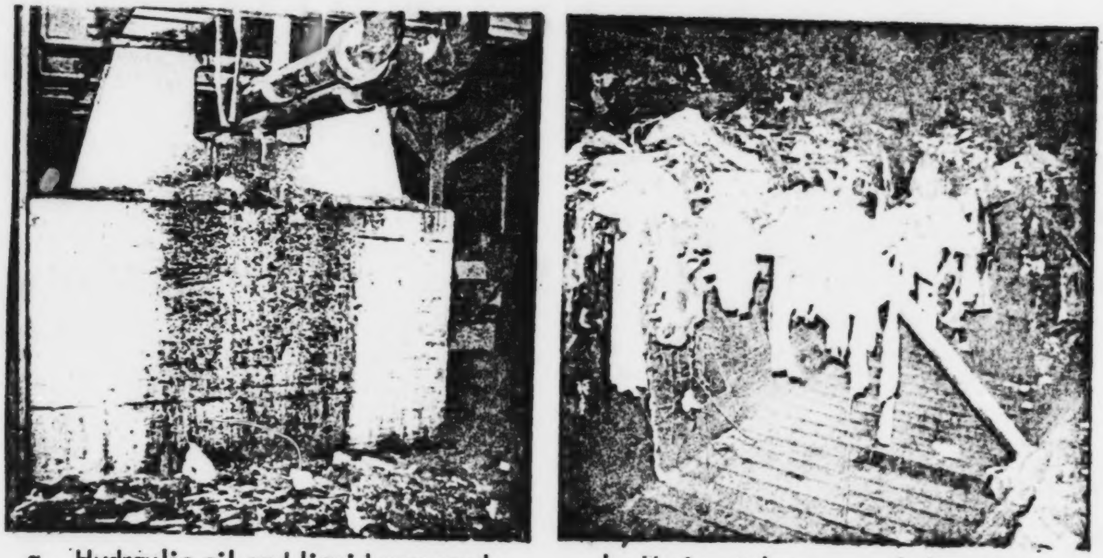
b. Incoming waste vehicle entrance



c. Cardboard sorters

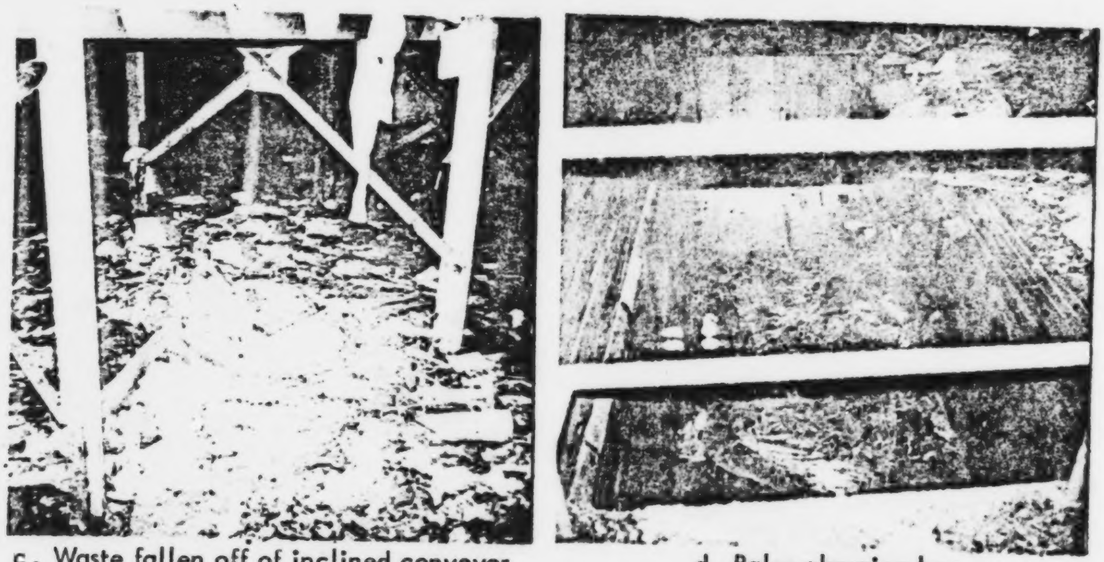
d. Front end loader placing waste on conveyor

PHOTOGRAPH 2-2
BALING PLANT OPERATIONS (II)



a. Hydraulic oil and liquid squeezed out under pressure

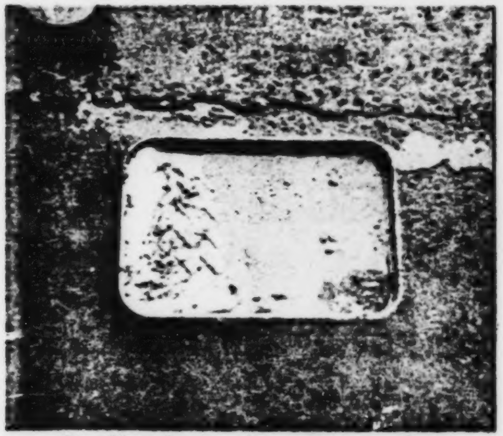
b. Horizontal conveyor belt and pit



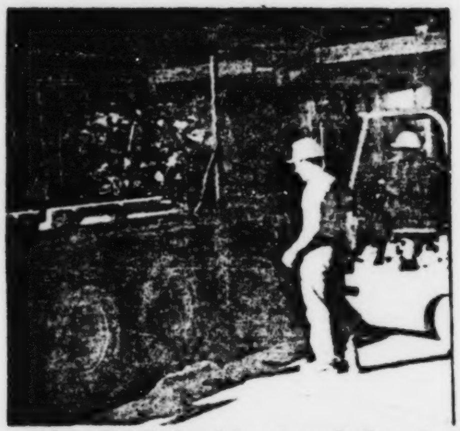
c. Waste fallen off of inclined conveyor

d. Baler charging box

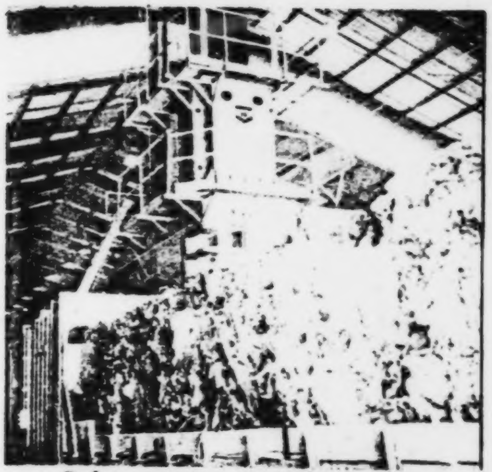
PHOTOGRAPH 2-3
BALING PLANT OPERATIONS (III)



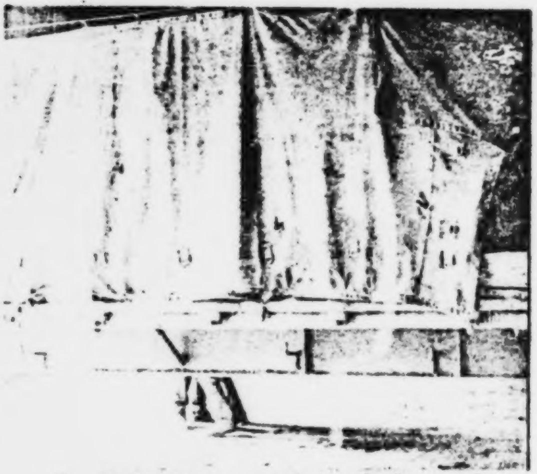
a. Small volume of squeezings from bale



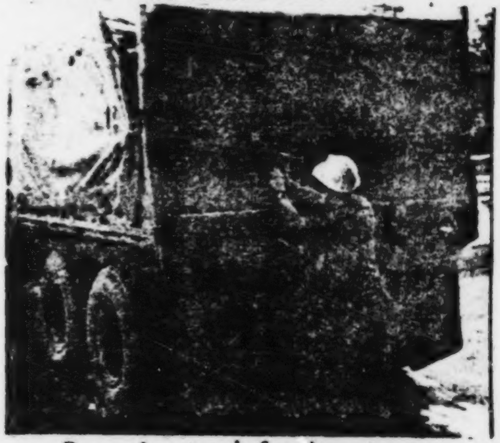
b. Truck backing into baler platform



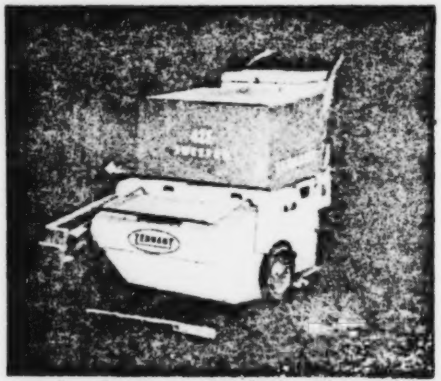
c. Baler and loaded bale truck



d. Protective curtain on bale truck



e. Preparing truck for departure



f. Sweeper for bale plant floor

PHOTOGRAPH 2-4
BALING PLANT OPERATIONS (IV)

SECTION 3
SOLID WASTE DESCRIPTION

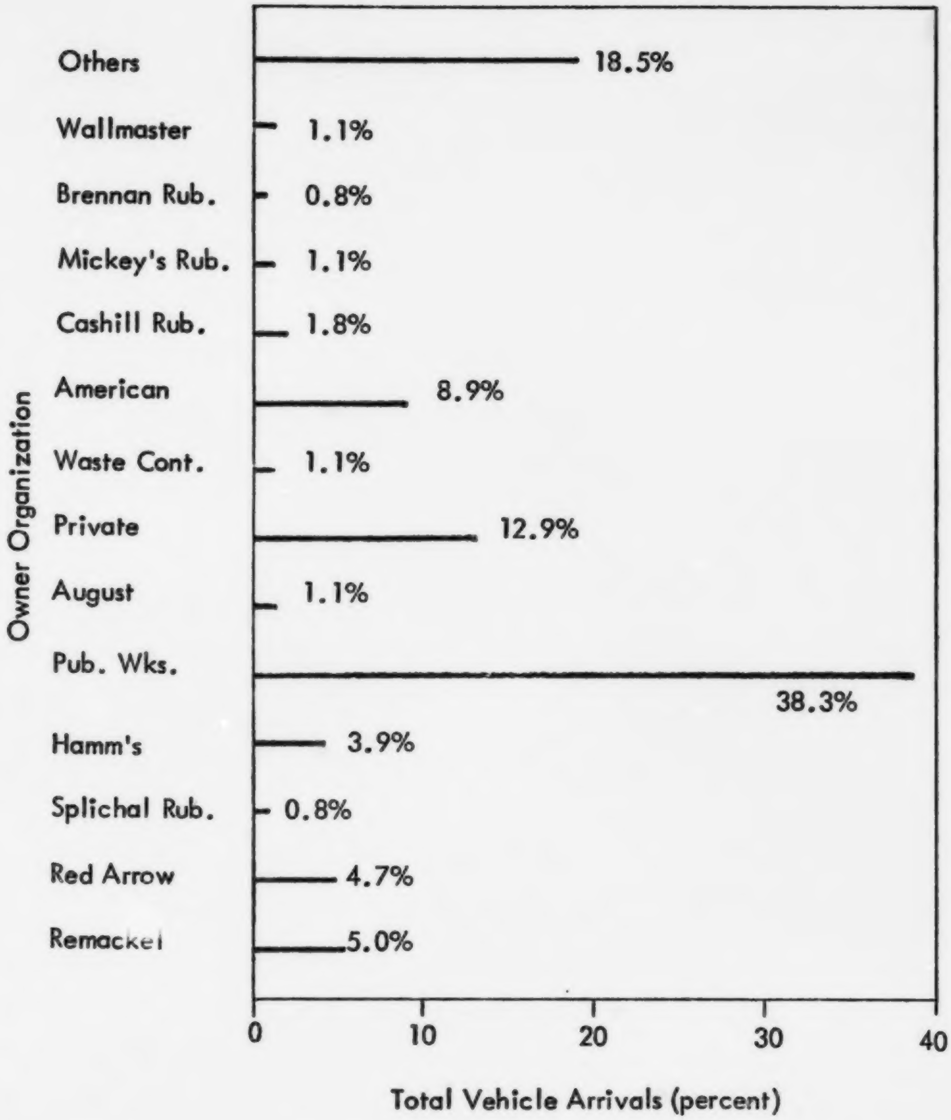
The baling operation depends to some extent on the nature of the solid waste. During the five-day study the incoming vehicles and waste characteristics were monitored. The American Systems baling plant gate attendant recorded the incoming vehicle owners, volume, and type of waste on the Gate Attendant Form provided by Ralph Stone and Company, Inc. (see Appendix A).

Representative samples of solid waste were removed twice daily, placed into a 510 liter (2 cu yd) bin and sorted into the following categories: paper, wood, metal, textile, plastic, rubber and leather, food, glass and ceramics, garden, rock and dirt, smalls (2.5 to 0.32 cm sieve), and fines (less than 0.32 cm sieve). Three additional 510-liter bins plus the two sorted bin fulls of waste were weighed each day to determine baler feed waste density. At the end of each day, a 9 kg (20 lb) sample was composited in proportion to the constituents in the two daily sortings for laboratory analysis.

The liquid squeezed from solid waste during baling was collected in several pans, and a bucket placed at points under the baler where leakage occurred. The volume of squeezings was measured and two samples were taken each day for laboratory analysis to determine pH, coliforms (total and fecal), BOD_5, Cl, SO_4, sulfides, TDS, and nitrogen series (NO_3, NH_3, and organic).

The St. Paul baler plant receives incoming solid waste from 6:00 a.m. to 8:00 p.m. The peak period is from 9:00 a.m. to 2:00 p.m., except during the lunch hour. This information is presented graphically in Figure E-12 for each day during the five-day study period, and in Figure E-13 for the entire weekly period.

The origin and size of the solid waste vehicles varied greatly. As can be seen in Figure E-14, almost half of the vehicle sizes were between 11.4 and 15.2 cu meters. The basis for this observation may be found in Figure 3-1, which indicates that over one-third of the incoming vehicles were St. Paul Public Works vehicles, which fall into this size category. Of the large vehicles, most were 57 cu meter (75 cu yd) vehicles owned by American Systems which hauled waste from the American Systems Midway Transfer Station in St. Paul. The percentage of vehicles under 3 cu meter (4 cu yd) in size corresponds well with the percentage of private vehicles arriving at the baler plant. This percentage may have been lower than usual in the time period studied because on Saturday, September 22, there was a city cleanup campaign in St. Paul. The public was allowed to dispose of refuse at several sites in the city without paying a fee. The St. Paul Public Works System vehicles brought these materials to the baling plant. On a volume basis, American Systems vehicles contribute 39 percent of the incoming waste, St. Paul Public Works vehicles 24 percent, private collectors 35 percent, and the public at large contributed 2 percent. The volume and type of solid waste received during and prior to the five-day study can be seen in Table 3-1. About one-half of the solid waste received was residential. The large amount of waste received on Monday, September 24, 1973, can be accounted for by weather conditions. Sunday evening and Monday morning



Legend: Arrivals on 9/20, 21
22, 24, 25 and 26, 1973,
combined.

FIGURE 3 - 1
SOURCES OF BALING PLANT SOLID WASTE

TABLE 3 - 1
INCOMING WASTE TYPES

Date 9/73	Total Solid Waste Volume Received (m^3)	Type of Waste Load (m^3)		
		Residential	Industrial	Commercial
13	1,004.9	443.16	314.34	247.45
14	939.76	439.40	289.36	211.0
17	679.6	317.84	170.87	190.93
20	1,203.3	528.9	362.69	311.8
21	1,133.4	435.51	361.36	336.32
24	1,315.7	637.3	422.1	256.38
25	1,117.7	610.1	245.4	262.2
26	834.8	371.49	241.3	222.98

experienced heavy rainfall. Many private haulers who had been driving to the competitive private sanitary landfill located outside of town to avoid paying the disposal fees brought their refuse to the baler plant during rainy weather to avoid the landfill, which reportedly became very muddy on wet days. The time lost due to trucks becoming stuck in the mud at the landfill compensated for the higher price charged at the baler plant at that time.

The density of the incoming waste can be seen in Table 3-2. The average density of 79.53 kg/m^3 (4.96 lb/ft^3) and the standard deviation of 17.46(1.09) indicates that the solid waste is not uniform. The process used to measure the density involved filling with solid waste a 510-liter (2 cu yd) bin which was provided by American Hoist and Derrick Company. The contents of the bin were then weighed by the sorting crew. The loader was used for filling the bin, taking a bucketload of refuse from the same area from which solid waste was obtained to load the conveyor, and dumping this bucketload instead into the storage bin. The level of mixing of the samples was, therefore, approximately the same as the level of mixing of the solid waste provided to the conveyor and the baler.

For sorting, the aforementioned bin was again filled by the loader. The contents were then sorted into standard categories by the sorting crew. The percentages shown in Table 3-3 are based on the wet-weight results of this sorting process. Once again, the standard deviation is large, indicating a large variation in incoming waste constituents. Table 3-4 shows an equally diverse moisture content for both the incoming solid waste and the bales. The organic content percentage is one of the few parameters that remained fairly stable.

The higher moisture content in the bale core samples may be due to one or a combination of the following factors: random variations due to differences between samples; the release of moisture from containers crushed during baling; and the diffusion of moisture throughout the bale material under the high baling pressure.

The main collection area for liquid squeezings was the area directly below the baler base. The squeezings had a consistency quite like oatmeal, rather than liquid. Therefore, two types of samples were taken. One sample was collected in flat rectangular pans (see Photograph 2-4). Another sample was collected in a bucket which had a piece of 0.32-cm (1/8-in) mesh hardware screening over the top. This method was used to strain the squeezings. It was though that there might be a difference in the two samples when analyzed in the laboratory, but as Table 3-5 indicates, there was in fact no noticeable difference. For the first three days of the study the volume of squeezings was checked only once per day because very little was generated. Beginning on Tuesday, the waste being baled was wet due to Monday's rain. (On Monday, there was a large amount of dry waste still on the floor of the baling plant from the City cleanup campaign which took place on Saturday. Thus, the refuse baled on Monday was dry despite the fact that it rained on Monday.) Therefore, on Tuesday and Wednesday the squeezings were being generated much more rapidly. As a result, the volume was checked three times per day on Tuesday and Wednesday. It also rained on Wednesday, resulting in very wet conditions in the baling plant. On this day, squeezings were also seeping out of the gathering ram and the compaction ram. On Wednesday, these volumes were also recorded. The squeezings were also much more watery on Wednesday and slightly lighter in color than the normal greenish-gray.

TABLE 3 - 2
INCOMING SOLID WASTE DENSITY

Date 9/73	Time	Sample Wt. (Kg)	Sample Vol. (cu. m.)	Density[a,b] (Kg/m^3)
20	8:30 A.M.	127.2	1.53	83.1
20	9:00 A.M.	119.1	1.53	77.8
20	1:30 P.M.	130.0	1.53	84.9
20	2:00 P.M.	155.0	1.53	101.0
21	7:30 A.M.	139.5	1.53	90.8
21	7:30 A.M.	149.5	1.53	97.4
21	9:00 A.M.	153.6	1.53	100.4
21	12:00 P.M.	106.4	1.53	69.5
21	12.00P.M.	170.4	1.53	81.4
24	7:00 A.M.	113.2	1.53	74.2
24	7:45 A.M.	105.9	1.53	68.9
24	8:05 A.M.	151.8	1.53	99.2
24	10:45 A.M.	127.7	1.53	83.1
24	11:30 A.M.	144.5	1.53	94.4
25	7:45 A.M.	86.3	1.53	56.4
25	7:45 A.M.	78.6	1.53	51.1
25	8:15 A.M.	139.5	1.53	90.8
25	11:00 A.M.	127.8	1.53	38.6
25	11:15 A.M.	137.7	1.53	89.7
25	1:15 P.M.	148.2	1.53	96.8
26	8:30 A.M.	126.3	1.53	82.6
26	11:30 A.M.	158.2	1.53	103.4
26	2:00 P.M.	92.7	1.53	60.6
26	2:30 P.M.	111.8	1.53	73.0
26	3:00 P.M.	87.2	1.53	96.5
26	3:40P.M.	93.6	1.53	61.2

[a] Average 79.53 Kg/m^3 (4.96 lb/ft^3); Standard Deviation=17.46 (1.09).

[b] From floor storage.

TABLE 3-3

BALER FEED WASTE COMPOSITION

Date 9/73	Percentage of Total, Wet-Weight Basis											
	Paper	Wood	Metal	Textile	Plastic	Rubber, Leather	Food	Glass, Ceramics	Garden	Rock, Dirt	Smalls 2.5 - 0.32 cm Sieve	Fines 0.32 cm Sieve
20	32.5	22.4	8.6	2.9	2.7	Neg	7.6	4.9	9.1	3.8	3.7	1.6
21	33.7	6.5	9.4	5.0	7.8	2.0	7.5	11.9	10.0	2.8	1.9	1.5
24	28.6	11.9	10.0	3.8	4.4	3.8	6.7	9.9	12.4	3.9	3.3	1.4
25	29.8	7.3	23.0	2.7	4.8	2.1	3.5	8.1	4.7	4.8	6.8	2.3
26	31.4	9.4	13.4	4.8	4.0	1.6	6.4	9.1	3.8	8.1	6.4	1.1
Average	31.2	11.5	12.9	3.8	4.7	1.9	6.3	8.8	8.0	4.7	4.4	1.6
Standard deviation	1.8	5.8	5.3	0.9	1.7	1.2	1.5	2.3	3.2	1.8	1.9	0.4

TABLE 3 - 4
ANALYSIS OF MOISTURE AND ORGANIC CONTENTS FOR UNBALED AND BALED SOLID WASTE

Date 9/73	Moisture Content (% dry weight)	Organic Content (% dry weight)
	Incoming Solid Waste Samples (Unbaled)	
20	54.6	60.0
21	15.3	74.8
24	48.5	89.0
25	37.9	83.9
26	71.0	73.5
Avg.	45.4	76.2
	Bale Core Samples[a]	
20	26.2	77.3
21	82.3	64.0
24	30.7	66.3
25	36.1	84.4
26	82.2	84.1
Avg.	51.5	75.2

[a] Samples taken within 15 min. of bale construction.

TABLE 3-5
CHEMICAL AND BACTERIOLOGICAL ANALYSES OF BALER LIQUID SQUEEZINGS

Sample		pH	Coliforms, MPN/100 ml		BOD_5 (mg/l)	Cl^- (mg/l)	SO_4^- (mg/l)	Sulfides (mg/l S)	TDS (mg/l)	Nitrogen Series (mg/l)		
Date 1973	Type[a]		Total	Fecal						NO_3	Ammonia	Org-N[b]
9/20	U	3.8	1,200	0	2,156	2,180	--[c]	--	--	--	0	--
9/21	U	4.9	24,000	0	0	1,460	--	--	--	--	0	--
9/24	S	4.1	2,000	0	3,300	2,620	3,800	5.0	64,310	22.9	308	2,817
9/24	U	3.5	2,100	0	3,940	2,760	--	--	--	--	104	1,604
9/25	S	4.1	11,000	0	3,200	2,020	--	--	--	--	112	--
9/25	U	3.5	1,100	0	2,550	1,795	3,900	16.8	43,640	11.1	153	1,232
9/26	S	4.6	4,600	0	2,005	2,250	4,000	10.0	40,820	11.6	464	1,171
9/26	U	3.2	2,800	0	2,070	965	4,400	12.8	49,730	70.6	0	2,352
10/2	S	4.7	24,000	0	--	--	--	--	--	--	1,445	1,764
10/2	U	4.0	7,300	0	--	--	--	--	--	--	0	730

[a] S = Strained, U = Unstrained. [b] Org = organic [c] -- Not enough sample for all analyses.

SECTION 4

BALE DESCRIPTION

A. Monitoring Method

A major aspect of the performance of solid waste baling systems is quality and production rate of the bales. These parameters were monitored in three ways. First, the control tower operator recorded the weight of the material loaded onto the scale for each bale. He also recorded the time of day for every 25th bale.

The second way involved a series of measurements made for every tenth bale. Each tenth bale was removed from the baler ejection platform and placed along the wall at the east end of the baling plant, near an auxiliary loading area. These bales were measured for maximum and minimum distances between faces on length, width, and height. These measurements were taken at times ten minutes, one hour, one day, and one week after bale production. The production time and ram pressure for each tenth bale were also recorded.

The third way consisted of taking three 5 centimeter (2-inch) core samples from each of two randomly chosen bales each day. A 1.5-horsepower industrial drill with a core-sampling bit was used. A standard 15.2 cm (6 in.) coring depth was attempted, but depths ranged from 5 to 25 centimeters (2 to 10 inches). The core samples did not remain intact but fell apart due to expansion immediately upon removal from the core sampling drill bit.

B. Results of Bale Monitoring

The bale production for the first shift can be seen on Figure 4-1. Production for the second shift can be seen on Figure 4-2. These figures show that bale production rate (the slope of the curves) is not constant throughout the day. Several work stoppages due to baler breakdowns are noted. On many days a characteristic slow-down can be seen near the end of each shift. This is common in most production plants which are labor-intensive.

Table 4-1 shows the production times for the tenth bales. The average production time is 1.73 minutes. This is defined as the period from the charging box lid closing until the ejection motion of the completed bale out the baler door is stopped. This time is different than the baler cycle time, which extends from the activation of the platen through the end of the ejection operation. The standard deviation of .16 minutes is 9 percent of the mean. This fairly low deviation indicates a relatively constant bale production time.

The measurement of the tenth bales was performed at successive times to determine the degree of springback of the bales. Figures 4-3 through 4-7 show the variation in the average value (average of maximum and minimum readings) for each dimension for the tenth bales for Day One (9/20) through Day Five (9/26), respectively. It can be observed that the maximum dimensions were measured one day following the production of the bales. Between this measurement and the one-week measurement, the dimensions

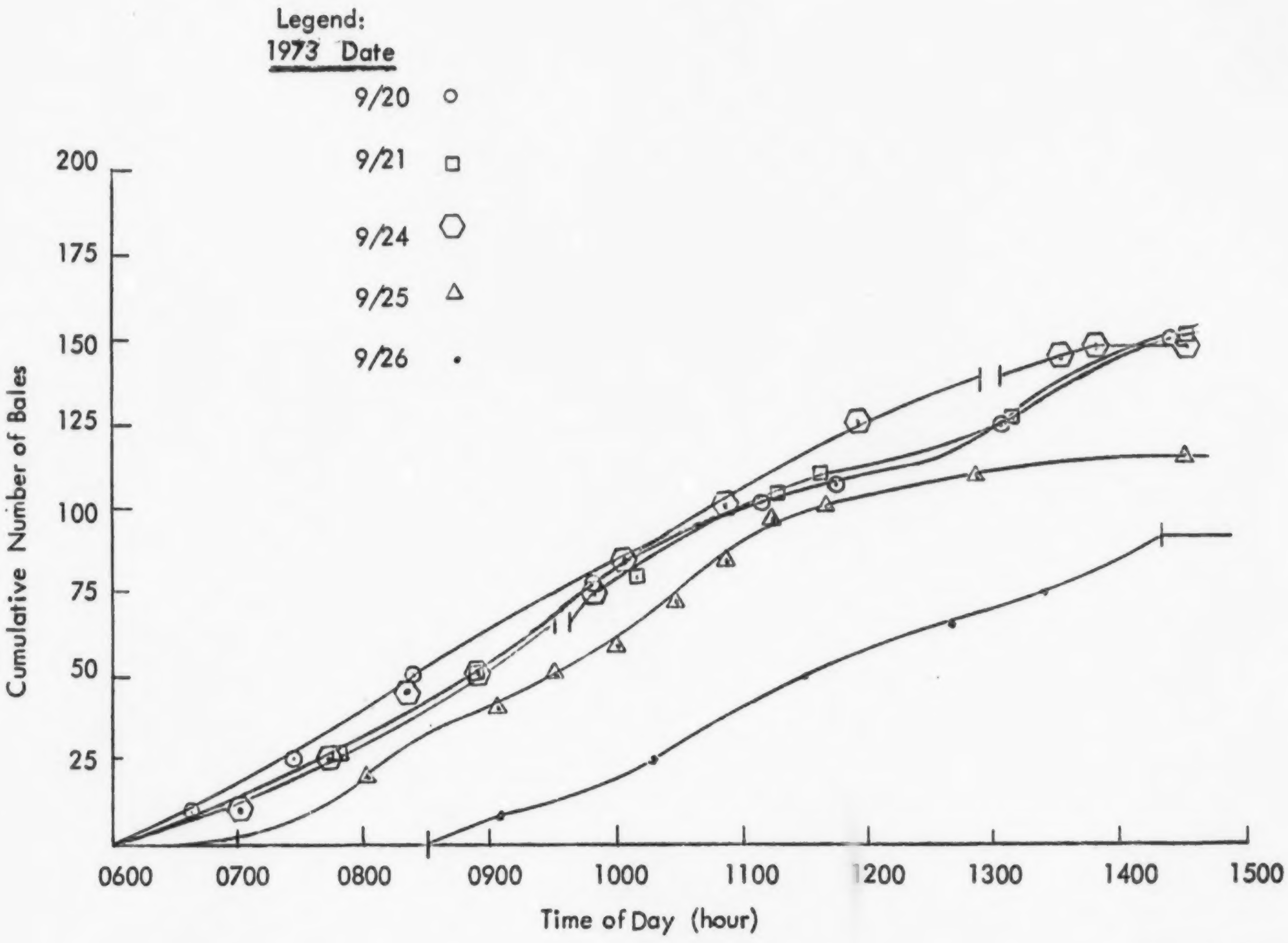


FIGURE 4-1
FIRST SHIFT BALE PRODUCTION

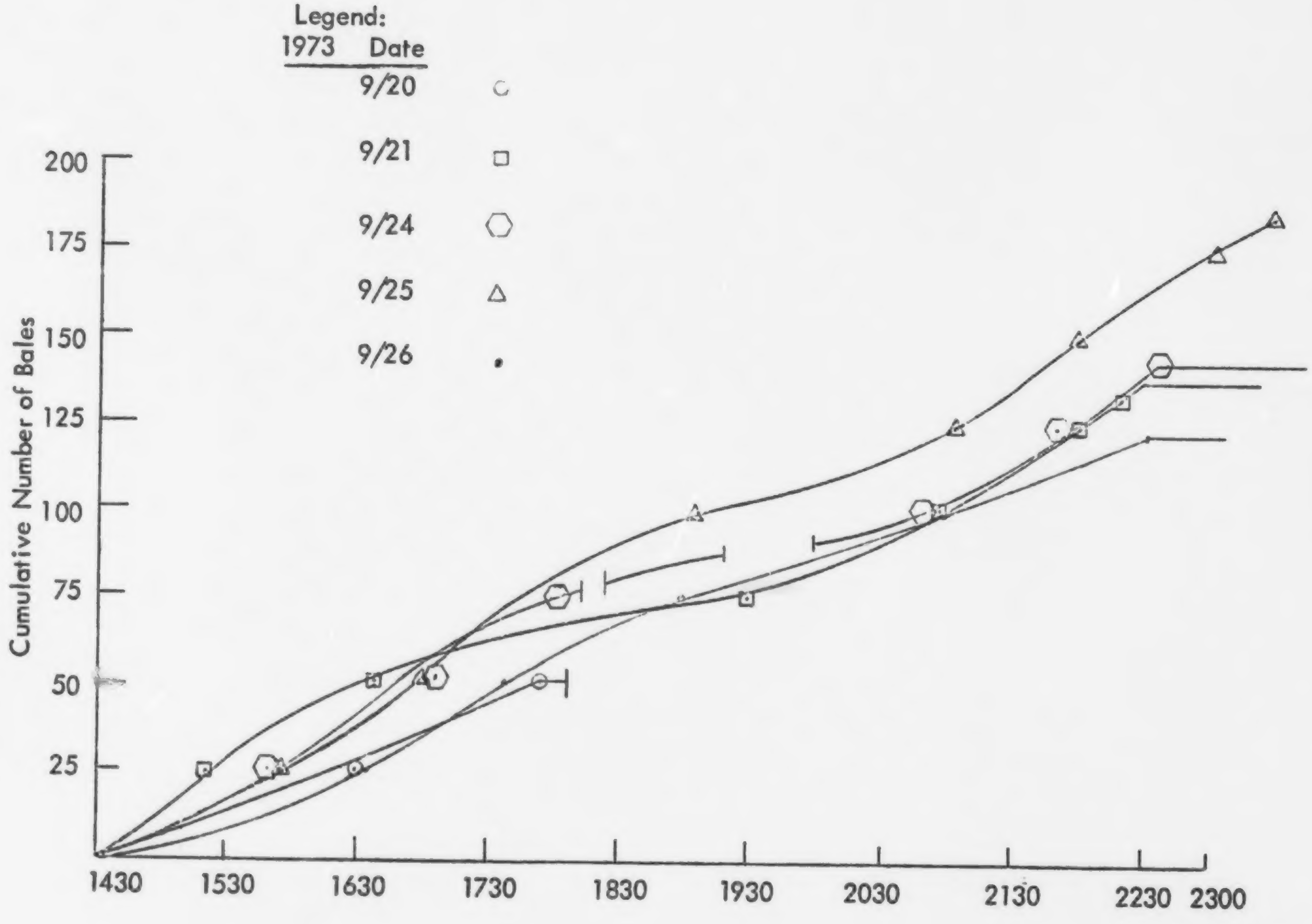


FIGURE 4-2
SECOND SHIFT BALE PRODUCTION

TABLE 4-1

TENTH BALE PRODUCTION TIMES

Sept. 1973 Days	Number of Tenth Bales Timed[a]	Average Production Time (min.)	Standard Deviation
20	15	1.799	0.11
21	14	1.757	0.26
24	13	1.647	0.08
25	9	1.764	0.13
26	11	1.679	0.15
Overall	62	1.731	0.16

[a] Tenth bale monitoring was done only during the first six to eight hours of plant operation, thus the number is less than one tenth of the total bale production for each day.

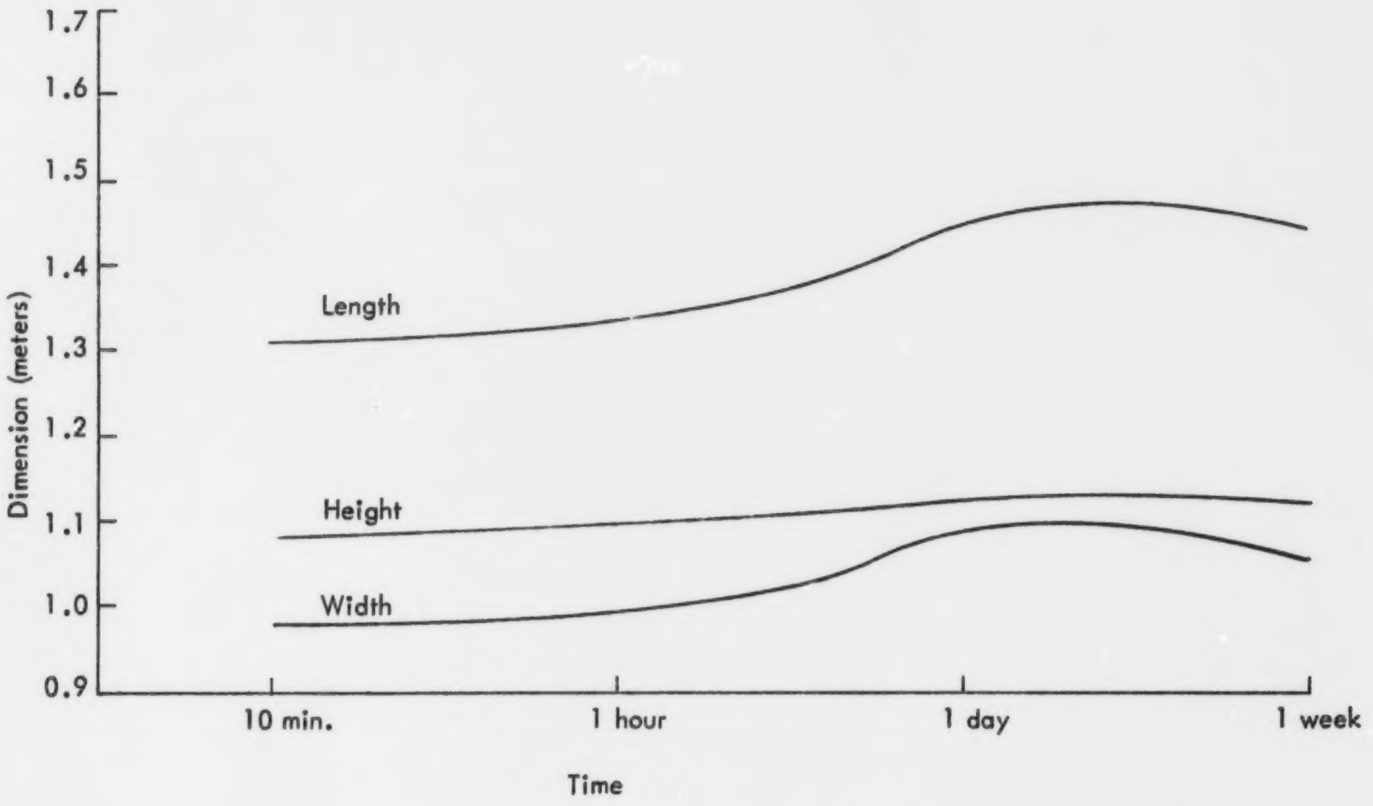


FIGURE 4-3
BALE SPRINGBACK-9/20/73

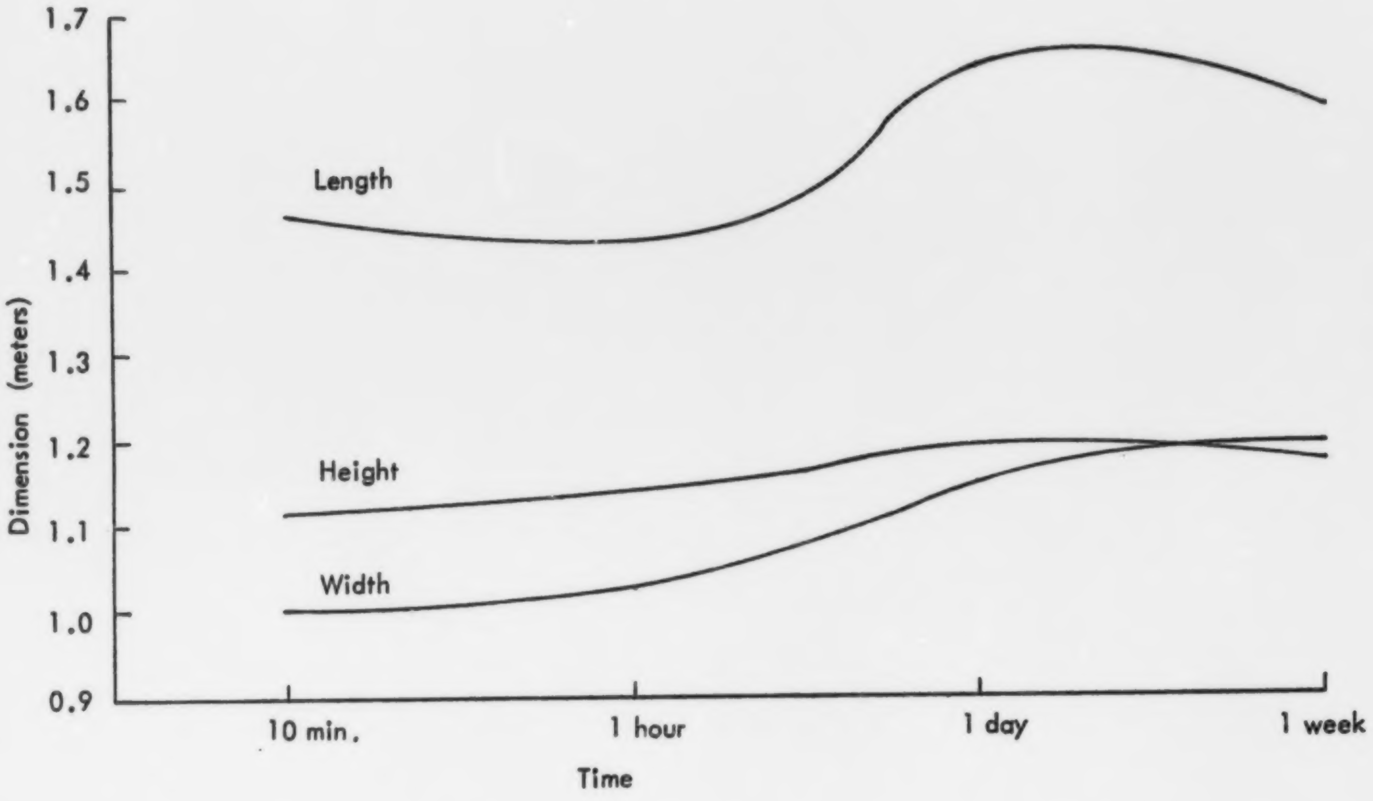


FIGURE 4-4
BALE SPRINGBACK-9/21/73

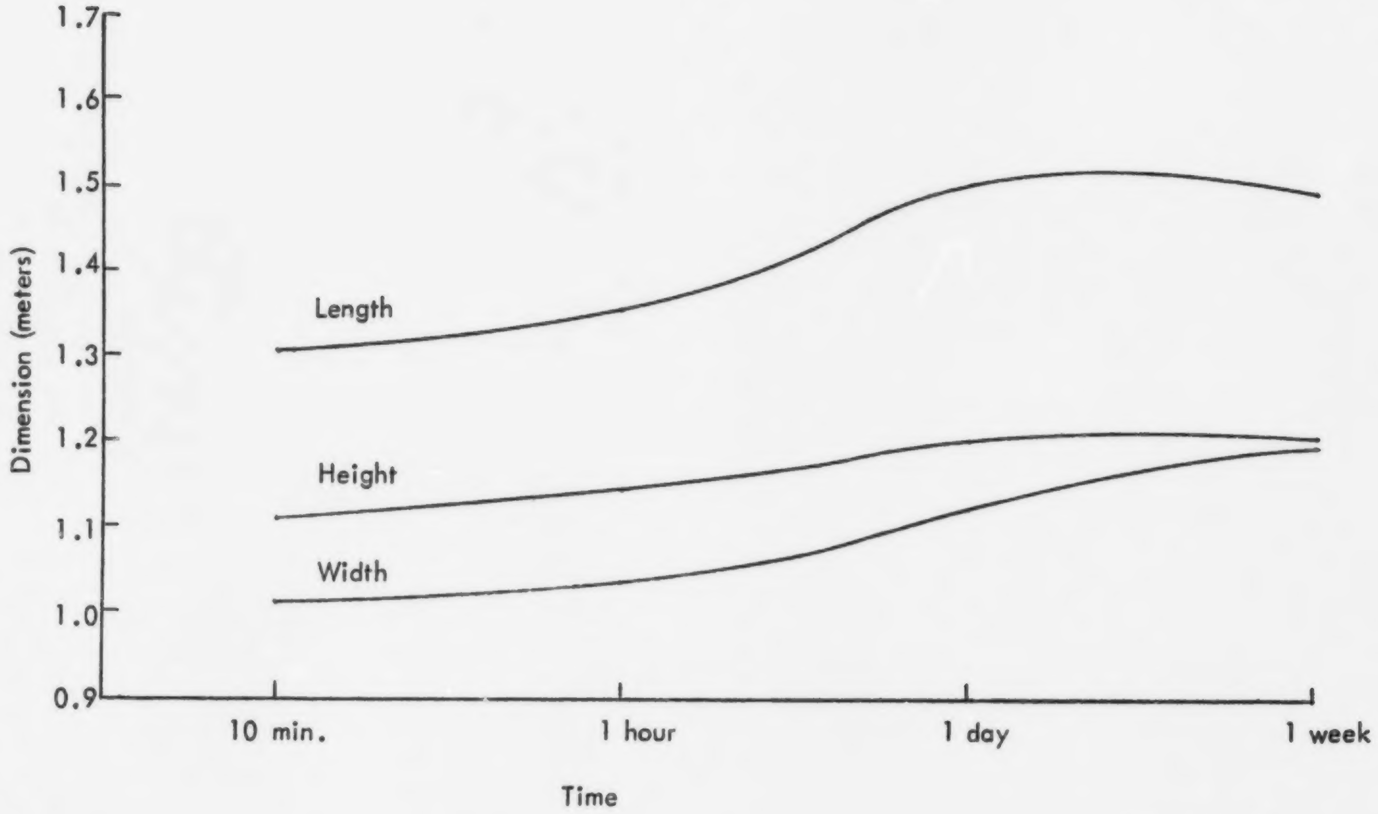


FIGURE 4-5
BALE SPRINGBACK-9/24/73

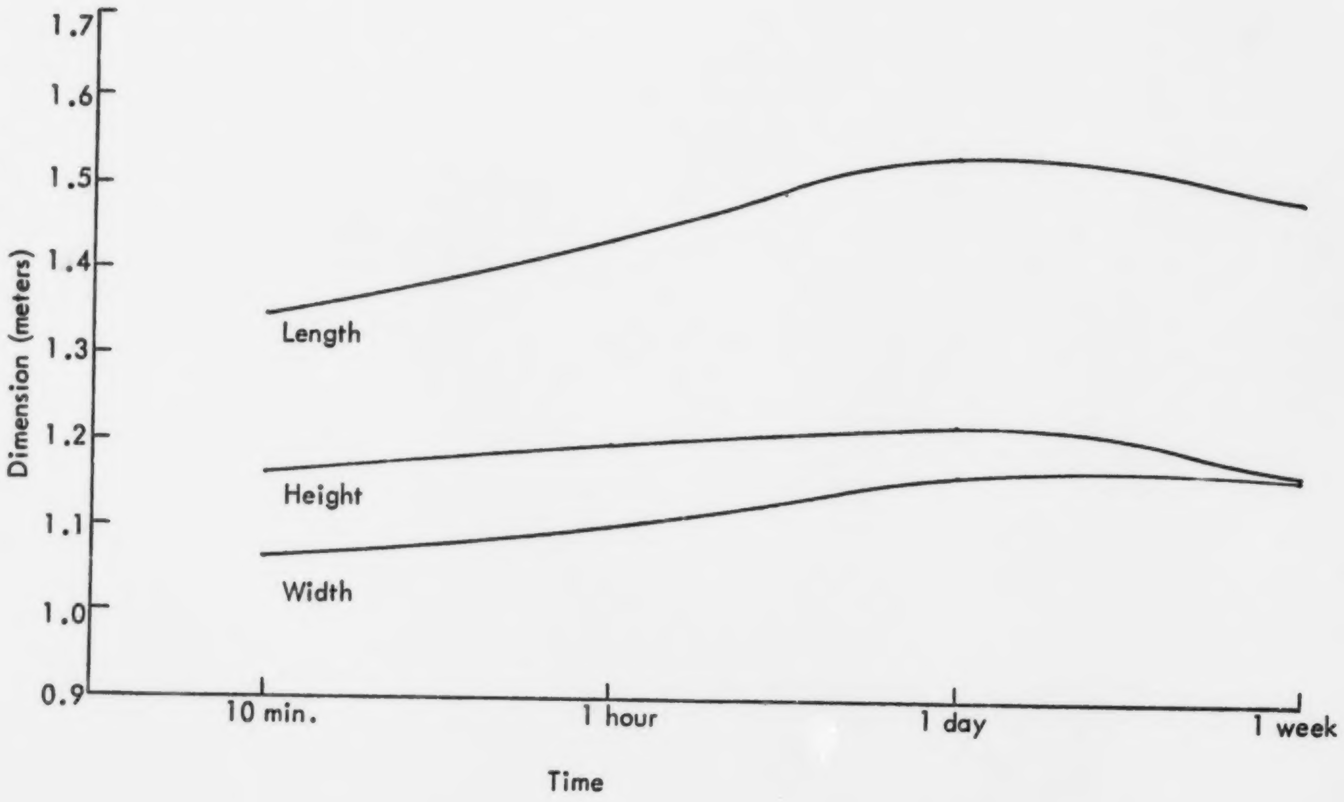


FIGURE 4-6
BALE SPRINGBACK - 9/25/73

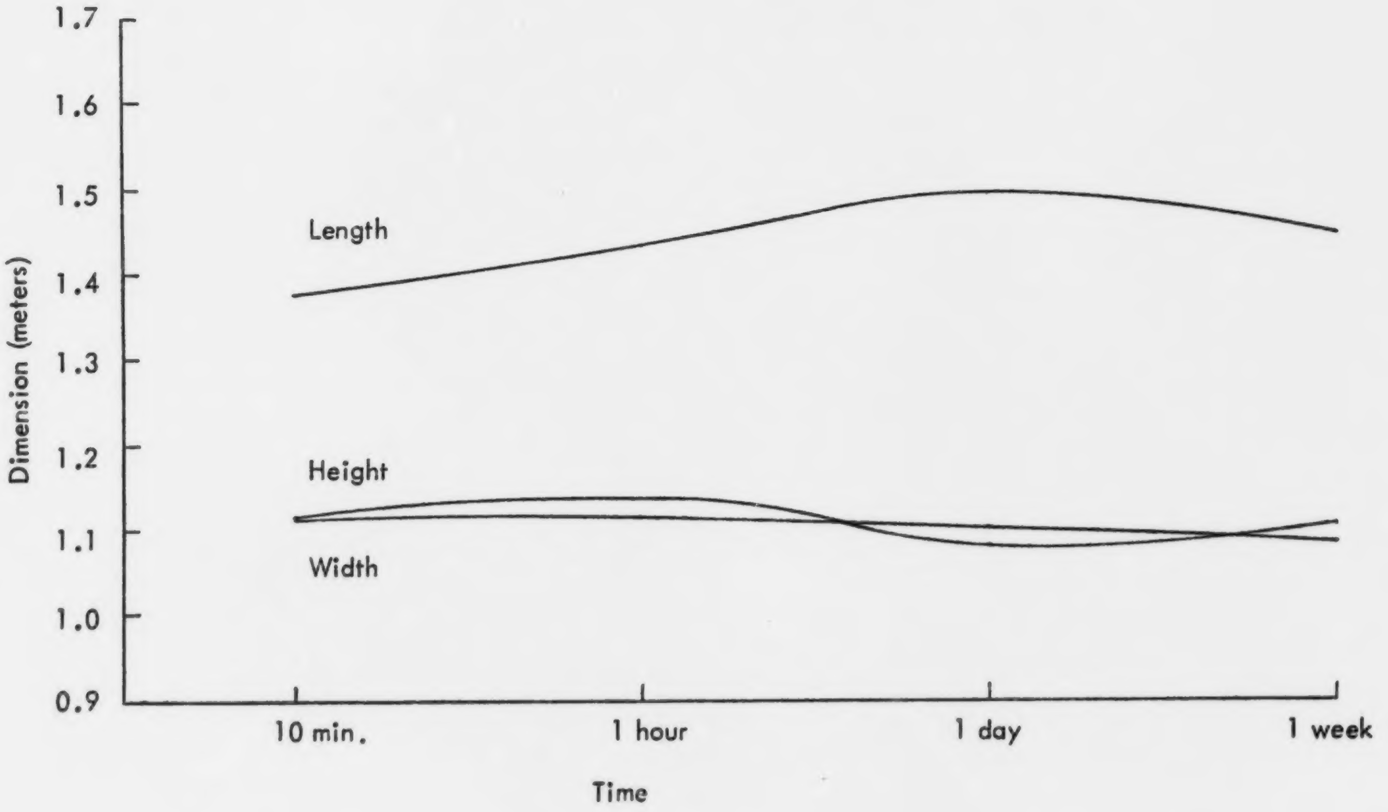


FIGURE 4-7
BALE SPRINGBACK-9/26/73

once again decreased. This seems to indicate a settling of the bales, perhaps due to evapo-transpiration of moisture. On Figures G-1 through G-5 the expansion is shown in terms of volume percentages. With the exception of 9/26, the same settling phenomenon is observed. A possible explanation is that the refuse being baled on 9/26 was very wet. Moisture causes paper, which comprises 30 percent or more of the refuse (see Section 3) to lose its elasticity. Percent linear expansion of the bales at one hour after production was: height - 2.5, width - 1.4, and length - 3.3; at one day after production, height - 5.7, width - 8.3, and length - 9.6; and at one week after production, height - 3.7, width - 9.6, and length - 10.8

The tenth bale measurements afforded a good opportunity to study bale uniformity. Tables G-1 through Table G-5 show the mean value, the standard deviation, the variance and the covariance for the maximum and minimum values of each dimension on Day One through Day Five, respectively. The bales may be seen to be fairly nonuniform. This cannot be attributed to the ram pressures used for the various bales, for the pressure only ranged from 1361-1588 kg (3000-3500 pounds) and was almost always the specification value, 1542 kg (3400 pounds).

By combining the data reported by the control tower operator and the tenth bale data, the densities of the bales can be obtained. The average bale weight, recorded by the control tower operator, was 1,282 kilograms (2,826 pounds), with a standard deviation of 50. Table 4-2 shows the average densities for each day's production of tenth bales. The wide range of densities (937 to 1579 lb/yd^3) indicates bale density nonuniformity.

The core samples were analyzed for moisture content and organic content, as were the daily 9 kg (20 lb) composite samples of the incoming waste. The results are shown in Table 3-4. Once again, nonuniformity was obtained, though the organic content is much more uniform than the moisture content.

The stability of the bales was monitored by direct observation of the number of broken bales during the five-day study period. One or two bales per day were seen to fall apart to some extent at the baling plant. Of the sixty-six tenth bales monitored, two (or 3 percent) fell apart at the baling plant. One occurrence was on 9/26, a very wet day. The surface materials of wet bales tend to slough off more readily than on dry bales. In addition, five (or 7.5 percent) of the tenth bales fell apart at the landfill in the course of the week of measurement. Three of these were produced on 9/26. It should be mentioned that these bales were subjected to much more handling than normal. Breakage at the bale plant thus may be seen to increase with increasing moisture in the incoming solid waste, and with increasing amounts of grass in the bales. However, the percentage of breakage at the baling plant seldom exceeds one percent under normal conditions.

Breakage at the landfill may be due to the operator mistakes. Occasionally, the operator will drop a bale from the forklift. In a quantitative observation of broken or damaged bales at the landfill, no distinction was made between unstable bales and bales damaged by operator mistakes. Of 582 bales observed, 14 bales (or 2.4 percent) were damaged or broken. Moisture contributes to the likelihood of the bales being

TABLE 4-2
TENTH BALE DIMENSIONS, VOLUME, EXPANSION, WEIGHT, AND DENSITY

Date 1973	Time Since Baled	Average Dimensions, meters (inches) Height	Width	Length	Volume, cu meters (cu yd)	Expansion (% by vol.)	Average Weight, kg (lb)	Average Density, kg/cu. meter (lb/cu yd)
9/20	10 min.	1.09 (42.8)	0.975 (38.4)	1.30 (51.3)	1.38 (1.8)	--	1290 (2843)	933 (1574.1)
	1 hour	1.10 (43.2)	0.995 (39.2)	1.33 (52.4)	1.45 (1.9)	5.1	"	889 (1495.8)
	1 day	1.16 (45.6)	1.09 (42.8)	1.46 (57.5)	1.84 (2.4)	33.0	"	702 (1182.6)
	1 week	1.14 (44.9)	1.06 (41.6)	1.46 (57.4)	1.76 (2.5)	27.1	"	735 (1239.3)
9/21	10 min.	1.12 (44.1)	1.01 (39.6)	1.47 (57.8)	1.65 (2.2)	--	1299 (2864)	787 (1325.7)
	1 hour	1.15 (45.2)	1.03 (40.5)	1.43 (56.4)	1.69 (2.2)	2.4	"	769 (1296.0)
	72 hours	1.20 (47.1)	1.15 (45.3)	1.64 (64.4)	2.25 (2.9)	36.4	"	577 (972.0)
	1 week	1.18 (46.3)	1.20 (47.1)	1.59 (62.5)	2.24 (2.9)	35.3	"	581 (980.1)
9/24	10 min.	1.11 (43.7)	1.01 (39.8)	1.31 (51.5)	1.47 (1.9)	--	1229 (2710)	837 (1404.0)
	1 hour	1.15 (45.1)	1.04 (40.8)	1.35 (53.3)	1.61 (2.1)	9.46	"	765 (1287.9)
	1 day	1.20 (47.3)	1.12 (44.1)	1.50 (59.1)	2.02 (2.6)	37.9	"	608 (1020.6)
	1 week	1.21 (47.5)	1.20 (47.1)	1.49 (58.7)	2.15 (2.6)	37.4	"	610 (1026.0
9/25	10 min.	1.16 (45.8)	1.07 (41.9)	1.35 (53.0)	1.67 (2.2)	--	1225 (2700)	734 (1236.6)
	1 hour	1.20 (47.2)	1.10 (43.4)	1.43 (56.4)	1.89 (2.5)	13.4	"	647 (1088.1)
	1 day	1.22 (48.2)	1.17 (45.9)	1.54 (60.5)	2.19 (2.9)	31.5	"	558 (936.9)
	1 week	1.17 (45.9)	1.16 (45.8)	1.49 (58.6)	2.02 (2.6)	20.9	"	608 (1020.6)
9/26	10 min.	1.12 (43.9)	1.11 (43.8)	1.38 (54.2)	1.71 (2.2)	--	1240 (2733)	725 (1223.1)
	1 hour	1.14 (44.8)	1.11 (43.9)	1.43 (56.4)	1.82 (2.4)	6.4	"	682 (1147.5)
	1 day	1.08 (42.6)	1.10 (43.5)	1.49 (58.8)	1.78 (2.3)	4.3	"	700 (1174.5)
	1 week	1.11 (43.6)	1.08 (42.7)	1.45 (57.0)	1.74 (2.3)	1.6	"	718 (1209.6)

damaged or unstable. The highest percentage of instability and damage (6 percent) occurred following a period of 20 hours of consecutive rain. Excluding wet bales from the data, the percentage of bad bales reduces to 1.8 percent.

Overall bale production for the five-day study period, in terms of weight of solid waste baled, average weight per bale, number of bales per day, hours per day per shift, and bales per hour, is listed in Table 4-3.

TABLE 4-3
OVERALL BALING PLANT PRODUCTION DURING 5-DAY PLANT MONITORING

Date 9/73	Total Wt. Per Days: Kg (tons)	Avg. Wt. Per Bale: Kg (lb)	No. Bales Per Day	Hours/Day/Shift		Bales/ Hour
				First	Second	
20	263,591 (290)	1,305 (2,878)	202	8	3.5	17.5
21	362,661 (400)	1,277 (2,816)	284	8	7.5	18
24	350,123 (386)	1,273 (2,807)	275	8	8	17
25	383,059 (422)	1,277 (2,816)	300	8	8.5	18
26	275,386 (303)	1,263 (2,785)	218	8	7.5	14
Average	326,964 (360)	1,278 (2,818)	256	8	7	17

SECTION 5

TRANSPORT NET DESCRIPTION

A. Loading Zone Plan

At the east end of the baler, facing the east door of the baling plant, was the loading platform. Hydraulic pushers positioned the bales on this platform and pushed the bales onto the transport vehicles. The vehicles therefore had to be backed up to the loading platform. Figure 2-4 shows the location of the ramp used to accomplish this. The area to the north of this ramp was used to park an extra vehicle. It was used for auxiliary loading of special bales (i.e., cardboard, scrap metal). This vehicle could be loaded using the forklift, since the floor of the baling plant was level with the bed of the vehicle.

B. Transport Vehicles

The transport network consisted of four enclosed cab tractors and five 12-meter (40-foot) flat bed trailers. The extra trailer was usually parked in the auxiliary loading area. The overall length of the cab and trailer when connected was 15 meters (48 1/2 feet.) The tare weight of the transport vehicles was 10,342 kilograms (22,800 pounds.) The cab tractor had two rear axles and the trailer a dual axle at the rear. As can be seen in Table 5-1, the transport vehicles were authorized by the Minnesota Department of Public Safety weight limits to carry a gross weight of 33,239 kilograms (73,280 pounds). With a tare weight of 10,342 kilograms (22,800 pounds), except for a leased vehicle, which has a tare weight of 11,022 kilograms due to a heavier truck tractor, this allowed in excess of 22,680 kilograms (50,000 pounds) of load. Since the normal bales averaged 1,281 kilograms (2,826 pounds) each, 16 bales could be carried on each transport vehicle. However, to allow a margin of safety for vehicle weight purposes, the usual load was 14 bales. Photograph 5-1 shows bale handling equipment.

C. Transport Operations

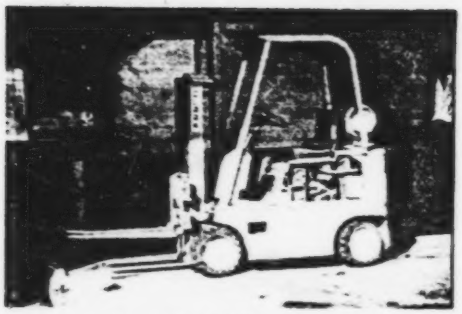
The transport labor force consisted of two vehicle drivers per shift. At any given time (on the average), one transport vehicle was being loaded at the baling plant. Another vehicle was traveling to the landfill with a full load. A third vehicle was parked at the landfill and was unloaded by landfill personnel. The fourth trailer was parked at the baling plant. The vehicle unloaded at the landfill was driverless. When a vehicle loaded with bales arrived at the landfill, the driver left this vehicle and entered the vehicle which had just been unloaded. He then drove this empty vehicle back to the baling plant. Simultaneously, the second driver left the baling plant and drove a full loaded vehicle to the landfill. Prior to leaving the baling plant, he backed an empty vehicle up to the loading platform. When the first driver arrived at the baling plant, there was usually a partially loaded vehicle at the loading platform. He therefore parked the empty vehicle in the eastern yard of the baling plant site. When the vehicle which was at the loading platform became fully loaded, he drove

TABLE 5-1
VEHICLE LOAD REQUIREMENTS[a]

	Weight in Kg (lbs)		
	Minnesota Max. Allowable Load	Bale Transport Truck Load	
		14 Bales	16 Bales
Single or Dual Wheel	4,077 (9,000)	3,532 (7,795)	3,851 (8,502)
Single Axle	8,154 (18,000)	7,063 (15,591) 7,221 (15,941)[b]	7,703 (17,004) 8,036 (17,737)[b]
One Vehicle or Combination of Vehicles	33,196 (73,280)	28,251 (62,364) 28,930 (63,864)[b]	30,811 (68,016) 31,491 (69,516)[b]
Four Axles 9.76 M (32 Feet) Apart	28,992 (64,000)	25,759 (56,364) 26,439 (58,364)[b]	28,320 (62,516) 28,992 (64,016)[b]

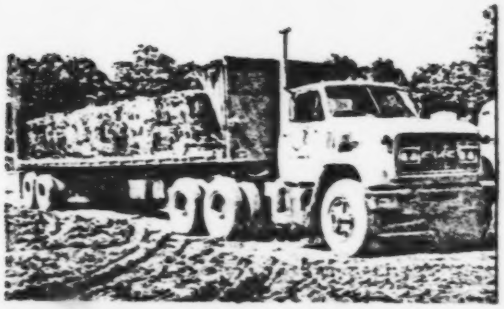
[a] Source: Minnesota Department of Public Safety.

[b] Leased vehicle with heavier truck tractor.

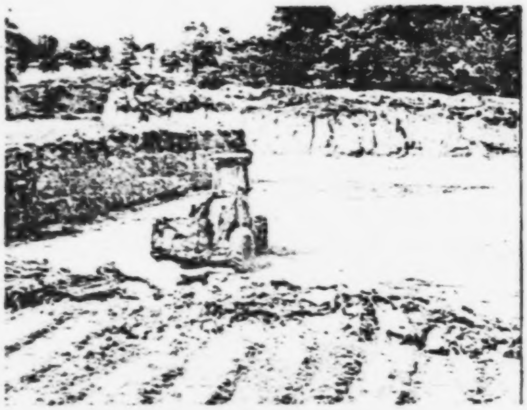


a. In-plant fork lift

b. Bale fill fork lift

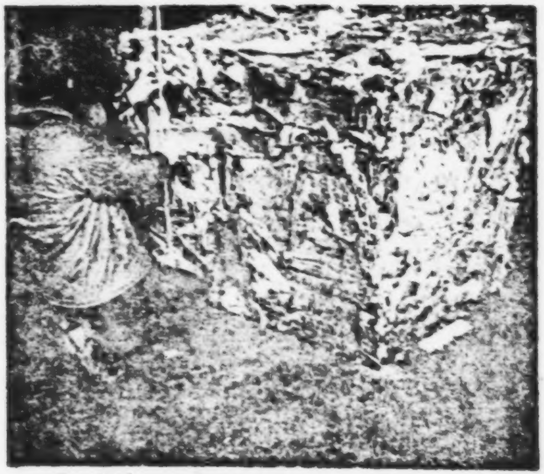


c. Truck prepared to unload



d. Placement of bales

e. Runoff from rainfall



f. Bale measurement

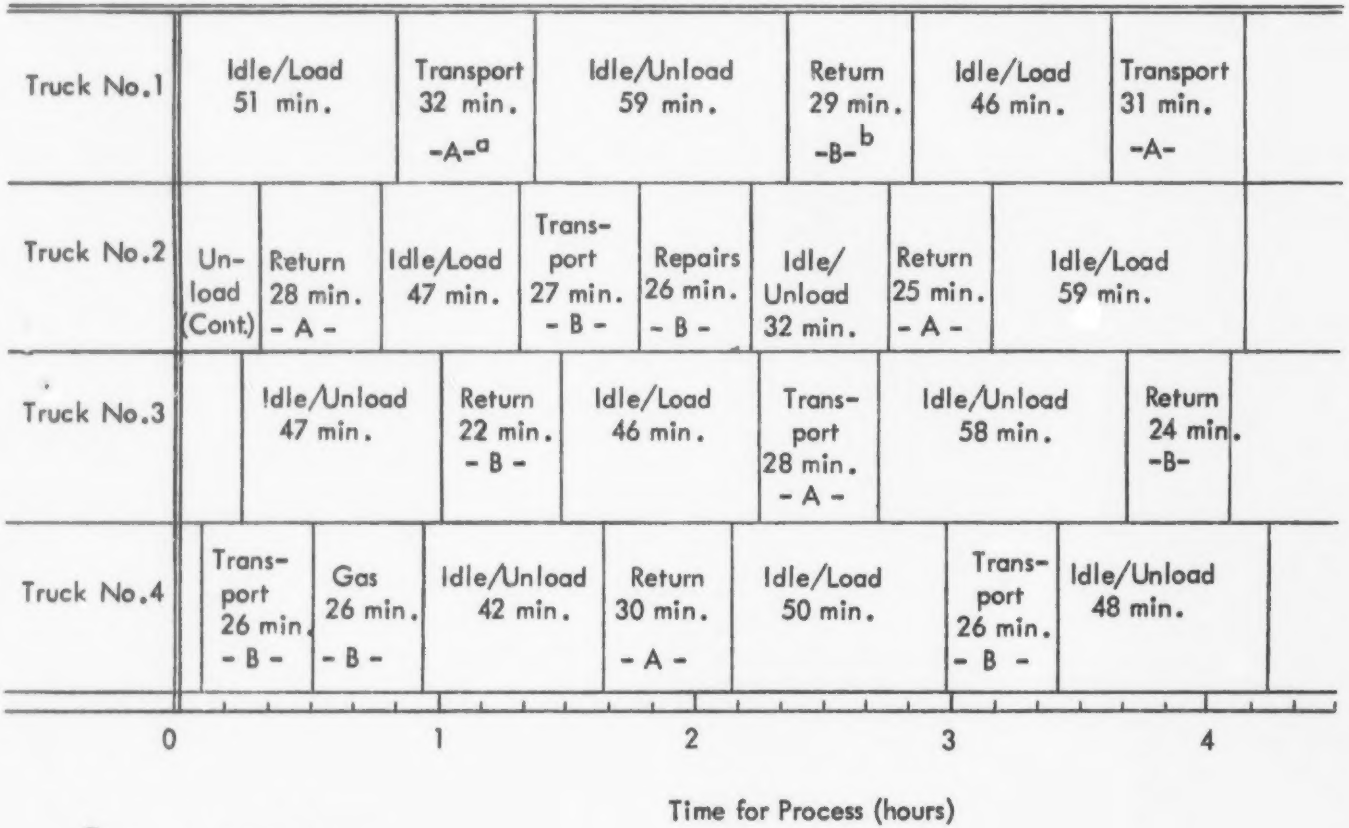
PHOTOGRAPH 5-1
BALE TRANSPORT AND PLACEMENT

it away from the loading platform and parked it in the eastern yard. He then positioned the waiting empty vehicle at the bale loading platform. He was then free to re-enter the loaded vehicle which he had left parked in the yard and drive this vehicle to the landfill. Upon reaching the landfill, an empty truck was waiting to be returned to the baling plant. He entered this vehicle and the cycle began again. A Gantt chart for this operation is shown in Figure 5-1.

The rigging and unrigging of the transport vehicle has been left out of the above discussion for the sake of clarity. The vehicles were equipped with meshed nylon curtains. These curtains were on two wire guides which ran the length of the trailer bed, as shown on Figure D-9. They were attached to the forward wall and to the rear posts at a height 1.2 meters (4 feet) above the bottom of the trailer bed. When the vehicle was empty, the curtains were at the front of the trailer bed, folded together. After the vehicle was fully loaded, the curtains were pulled back to the rear of the trailer. This required two men, one on each side, since the curtain sides and top were a single piece of material. The curtains were therefore one unit and each side had to be pulled evenly. This rigging process was initiated at the loading platform just prior to the pushing of the last two bales onto the trailer bed. The curtains, once pulled over the bales, were attached at the bottom to the trailer bed by several sets of hooks spaced along the length of the trailer. After the vehicle pulled away from the loading platform, the piece of plywood which served as the tailgate was put in place. This was done by the vehicle driver either before or after he backed an empty vehicle up to the loading platform. The tailgate slid into grooves located in the two rear posts and was secured in place by a chain that attached to hooks on the two rear posts. The placing of the tailgate could be performed by one man, but the vehicle driver usually received help from either the maintenance man or the forklift operator. Observed times for the two rigging operations for one, two and three men are shown in Table E-12.

When the fully loaded vehicle arrived at the landfill, it was unrigged to provide access to the bales. The vehicle driver, assisted by the landfill worker, pulled the curtains forward and secured them with a cord on the forward trailer wall. The driver was then free to drive the waiting empty vehicle from the landfill. The landill worker removed the sideguards from one side of the trailer bed so that the bales might be removed. After removing the bales, he prepared the vehicle for the return trip to the baling site. This involved sweeping off solid waste that remained on the trailer bed, replacing the sideguards, and removing the tailgate and placing it on the trailer bed near the forward wall.

The drivers also had additional duties. The drivers assisted in the daily baling plant clean-up, and while at the baling plant waiting for a truck to be loaded, they might have been requested to operate the floor sweeper or the small loader. They were also responsible for the normal maintenance of the vehicles.



[a] Refers to Driver 1.

[b] Refers to Driver 2.

FIGURE 5-1
GANTT CHART OF TRANSPORT TRUCKS

D. Route Plan

The landfill was approximately twleve miles from the baling plant. There were two routes used to reach it, shown on Figure D-10. The choice of routes was at the driver's discretion. The Concord Street Route was slower with more traffic signals. The Robert Street Route, though faster, had steep hills that some drivers preferred to avoid. Both routes traversed shopping areas. The Concord Street Route passed through an older commercial district with narrow streets, while the Robert Street Route was primarily through suburban shopping centers with wide streets.

SECTION 6
BALE LANDFILL EVALUATION

A. Landfill Description.

1. Location of Landfill. The landfill is located in an area of Dakota County known as Inver Grove Heights, approximately 19 kilometers (12 miles) south of the baling plant (shown in Figure D-10).Railroad tracks determine the northern and western boundaries: the Suburban Gas Company (from which the American Hoist and Derrick Company acquired the fill site) is situated beyond the tracks to the north of the landfill.

2. Landfill Site. Figure D-11is a topographic map of the landfill site. The railroad tracks are shown and can be compared with the layout of Figure D-10. The ultimate drainage is also shown. There is a small pond north of the site into which the area drains. This pond drains a large area in addition to the landfill site. A cow-pasture lies immediately south of the site. The area between the two railroad tracks comprises 0.12 square kilometers (29.9 acres). The area east of the Chicago and Northwestern Railroad contributes another 0.04 square kilometers (8.9 acres). The area between the two tracks is roughly a 365 meter (1200-foot) square with a large cutout of the northwest corner. The area east of the tracks is roughly a 200 meter (700 foot) x 150 meter (500 foot) rectangle with the long dimension running north-south .

B. Landfill Monitoring.

Copies of the forms used to record observations of landfill operations and environmental conditions are included in Appendix F. This section explains how information recordedon the data forms was obtained.

1. Bale Spacing (Weekly). The working face was divided into ten sections of equal size, then the middle bale in each section was selected for the spacing measurements. One day each week field observers placed a triangular wedge perpendicularly between the selected bale and two neighboring bales along two edges to determine the average distance between bales.

2. Landfill Operation Record (Weekly). Observers made general notes on the condition of the landfill to determine operation effectiveness. Weekly records included a description of the soil covering process (10 minute periods), a count of broken bales (from observations of random samples of 100 bales on the exposed working face), and observations of surface water pool area and depth to identify drainage problems.

3. Landfill Environmental Record (Weekly). An area approximately 30 m (100 ft) square directly adjacent to and below the working face was defined as the litter sampling plot. Litter items were either counted individually or their total area estimated one day each week. The observers quantified the dust problem by estimating the fraction

of the landfill area capable of producing a dust column due to vehicular traffic. The access road was initially divided into 30 meter lengths, then observers used a random number table to decide which section to use to describe dust conditions each particular week. Numbers and kinds of non-insect vectors (birds, rats, dogs, etc.) were also noted.

4. Time and Motion Studies (Weekly). Investigators used precision stopwatches and a time-study clipboard to time equipment and labor tasks such as forklift placement of bales, cover soil carrying and placement litter and truck clean-up, and other related task performances.

5. Fly Emergence Studies. Special studies of fly emergence were undertaken during periods from April 30 through May 22, 1974 and May 28 through June 22, 1974. Ralph Stone and Company, Inc., personnel conducted the routine daily monitoring of fly emergence traps.

Each month, two 4.6 m by 4.6 m (15 ft by 15 ft) test plots (over bales) were defined, then covered with a moist soil layer. Initially six fly emergence traps (two were later destroyed), each with a 1 m (3 ft) square base and 30 cm (1 ft) high were placed 1 to 1.6 m (3 to 5 ft) apart on each of the two test plots, as shown in Photograph G-1a. Photograph G-1b shows the traps, and Figure G-6 illustrates individual trap components. Flies emerging from the baled solid waste were attracted to the light in the glass, then trapped. The field investigator collected and counted trap contents daily, then sent them to the company laboratory for identification. The screen in the jar and a tight soil seal around the box prevented fly escape. The emergence tests were conducted over a period of time long enough to allow egg hatching, larval development, and adult metamorphosis (about 21 days).

C. Results and Discussion.

1. Landfill Operation Description. The bales were transported to the landfill on a flat bed tractor-trailer truck as seen in Photograph D-2a. The bales were removed from the transport vehicles by an operator using an Allis-Chalmers 840 articulated forklift as seen in Photograph D-2b. The bales were stacked three-high in tiers and side-by-side to form horizontal rows which are usually 80 to 120 bales long (Photograph D-1b). Since the bales were situated with their longest dimension aligned longitudinally along the direction of the row, the row dimensions were about 3 meters (12-1/2 feet) high by 90 to 150 meters long by about 1 meter wide. There were 240 to 360 bales in a three-high tiered row, amounting to approximately 480,000 kilograms (450 tons) of solid waste. The rows were constructed one at a time. The first three bales were placed on the ground, then two bales were placed on the second level and one placed on the top of the second level. This provided a starting point, as shown in Figure 6-1. The succeeding bales were placed up against this first set of bales in sets of three: bottom bale, second level bale, and lastly, the top bale. This procedure provided continual stability to the row.

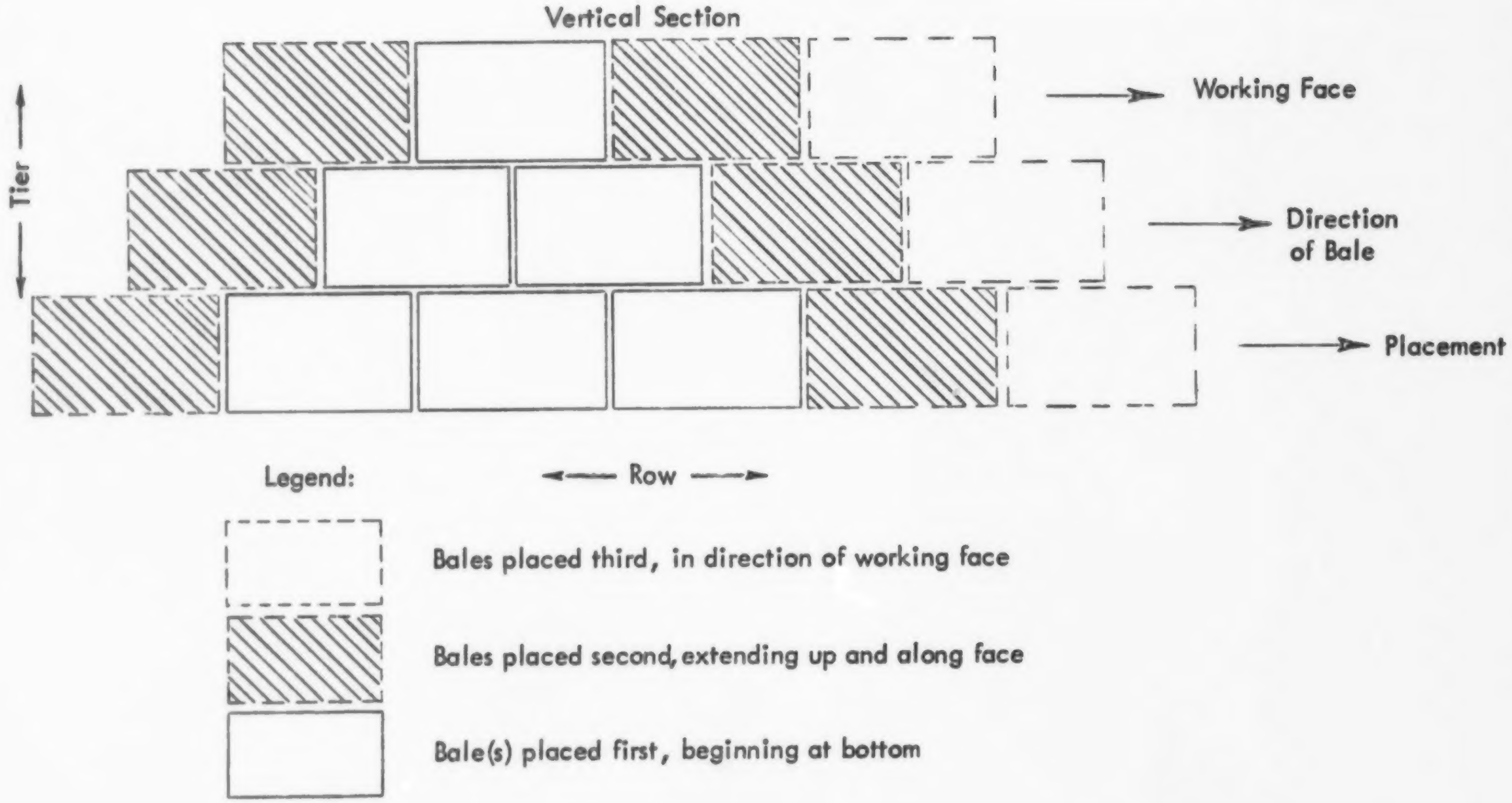

Vertical Section
Tier
Working Face
Direction of Bale
Placement
Row
Legend:
Bales placed third, in direction of working face
Bales placed second, extending up and along face
Bale(s) placed first, beginning at bottom

FIGURE 6-1
ST. PAUL BALEFILL PLACEMENT PROCEDURE

The placement of the soil cover was accomplished using a Trojan 4000 loader with a 3.8 cubic meter (5 cubic yard) bucket (see Photograph D-3). The number of rows which were placed together prior to applying soil cover was determined by the landfill geography and the availability of cover. Ideally, the first row was placed against an embankment and succeeding rows continued along and out from the embankment. When this was done, the loader excavated cover soil from the embankment and covered the first rows, then continued to cover away from the embankment. Using this procedure, the loader traveled only on top of covered bales. Daily cover was not always completed. The frequency of cover soil application was observed to be closer to once or twice weekly.

The roads were kept hard-packed by drag-scraping a large steel support beam frame along their surface. The loader was observed performing this operation. The loader was also used to clean up litter, sweepings, and broken bales. This material was pushed to the side and covered immediately with soil.

The landfill personnel consisted of two operators, one of whom served as a leadman. The leadman saw that the orders of the superintendent were carried out. Both operators were responsible for the maintenance of the landfill equipment. One operator worked the first shift, 6:00 a.m. to 2:30 p.m. The leadman was responsible for the second shift, but often arrived before 2:30, occasionally as early as 10:00, to stockpile soil cover, maintain the roads, or perform other peripheral tasks, while the other operator concentrated on unloading bales from the vehicles.

There was only one structure at the landfill, a trailer located near the entrance alongside the access road. There was no running water or electricity. Sanitation was provided by an outhouse behind the trailer. A water tank and a fuel tank were located nearby the trailer. A generator and a set of mercury vapor lights were kept at the landfill and used to illuminate the working area during the evening when the second shift was in operation.

2. Landfill Evaluation. Ralph Stone and Company, Inc. personnel evaluated the St. Paul balefill using an EPA scoring method (Table G-9). The EPA evaluation was designed to determine the quality of normal sanitary landfills; scoring was adapted to suit the circumstances of the balefill. The balefill was thus rated "minimally acceptable"; the low score was due primarily to a lack of daily earth cover, which may be unnecessary due to its high density,cohesiveness of baled materials, and vertical working face.

3. Monitoring Results. Data were collected by operational and environmental monitoring; observations were made on bale spacing, surface water accumulation, broken bales, cover soil application and thickness, litter, dust, vector foraging, and fly emergence.

a. Bale Spacing. Table G-6 displays the results of bale spacing measurements. Entries are listed chronologically and show, for a given day, the maximum, minimum, and average space (plus standard deviation between the 10 sample bales and their neighbors along a long and a short bale face edge . The average space between bales was generally much greater along the long edges than the short edges, which can be explained by the stacking procedure. When bales were stacked, the forklift could position them flush against bales on either side more effectively than it could fit them flush against the bales directly behind the bale being placed. Once the loosely packed bale "walls" reached a certain height, they tended to lean due to variations in dimensions of the bales. Generally, bale size irregularities contributed to inter-bale spaces in both directions. The majority of the bale spacing measurements were taken from above the stacked bales until the last two months. These last measurements included observations of side spacing between bales taken from a position in front of the working face. The data in Table 6-2 indicates the spacing trend reversed; e.g., the minimum space was measured on the longest bale face.

b. Surface Water. Puddles were observed on 10 of 42 monitoring days, and only once were they estimated to cover more than 15 percent of the fill surface. The surface water observed on 3/3/74 accounted for almost half the total observed for all days; including that date the average area covered with water for the 10 days when water was present was 68 sq m (728 sq ft), and without that date the average was 39 sq m (419 sq ft). Over the 42 days, the average submerged area was 16 sq m (173 sq ft); over 41 days (excluding 3/3/74), 9 sq m (92 sq ft).

c. Broken Bales. The number of broken bales out of a sample of 100 bales was determined on 11 occasions. Numbers ranged from 0 to 7, with the average 2.2; from this it can be estimated that a minimum of 2.2 percent of all bales in the fill were broken at any given time.

d. Cover Soil. Since both monitoring and fill covering with soil were undertaken once a week (roughly), they rarely occurred on the same day. On the four days (of 42 total) when covering was observed, an average of 15 cm (6.1 in), ranging between 13 and 20 cm (5 and 8 in), of soil was spread over the bales.

e. Litter. Numbers of discrete pieces of litter larger than 6 sq cm (1 sq in) were recorded in 3 m (10 ft) square areas of three locations below the working face, above it, and along the fill access road. Table G-7 briefly summarizes the results. It was assumed that extremely high values of litter were due to broken or exposed bales, and thus did not represent normal conditions of litter escaping from bales. Therefore, the data is presented in Table G-7 for all litter values (upper half of the table) and for values that were grouped closely in magnitudes less than 100 (lower half). The data in the lower half would indicate the litter level on typical days, and the data in the upper half for days when broken bales occurred. The relative magnitudes of the counts for the three locations are directly related to the amount of solid waste exposed. Thus, the values below the working face, where trucks were unloaded and swept off, had over twice the litter observed in the other two locations.

f. Dust. Seven visual dust observations were made between late May and late August to determine the height of dust columns; the dust height provides an indication of its potential to travel off-site and cause detrimental environmental impact. Dust was not observed during other times of the year due to rainfall, snow cover, or frozen ground. All sample dust columns were attributed to cars or trucks, and averaged 2 m (8 ft) in height over a range of 1 to 4 m (4 to 12 ft).

g. Vectors (non-fly). On only 9 days were any non-fly vectors observed; all of these were birds. Numbers of birds seen varied between 100 and 3. Averaged over all observations (34), the typical number birds visiting the fill was about 4.

h. Fly Emergence Studies. The fly emergence traps were placed on cover soil averaging 15 cm (6 in) in depth and on uncovered bales. Though the emerging insects were all classified as "flies," technically six families represented Order Diptera and three families represented Order Coleoptera. Representative samples of flies collected between 4/30/74 and 5/22/74 and between 5/28/74 and 6/22/74 were sent to and identified in the Stone company laboratory. Table G-8 shows the different families which were collected from individual traps for both monitoring periods. Table 6-1 lists the quantitative results of the St. Paul fly studies and compares them with similar studies undertaken in Oceanside, California, where fly emergence tests were conducted on normal solid waste with and without soil cover and sewage sludge.

Several factors should be considered when interpreting the information presented in Table 6-1. First, Oceanside data included only Dipterans; relative frequencies of the two orders were not available for St. Paul. Area climates differ greatly; Oceanside has fairly mild weather year-around, with a sporadic winter rainy season, and St. Paul experiences summer and winter temperature extremes and much more annual precipitation. These climatic differences plus geographical differences can affect the type, number, and breeding seasons of flying insects.

From the data collected, the cause of very high fly figures during the first couple of days in St. Paul cannot be isolated. Trapping technique, age of the waste prior to disposal, local fly abundances, operational procedures, or a combination of these factors could explain the differences between St. Paul and Oceanside. One possibility is that some solid waste may have been stockpiled in the baling plant for one or two days in addition to storage at the source (households, etc.) for up to one week. The baling plant open storage would allow additional eggs to be placed by adult flies in the plant. Also, the extended time period between generation and landfill disposal would allow for adult fly emergence on the first day after bale placement in the landfill.

Despite the above problems with data interpretation, the following conclusions may be drawn from the fly emergence studies.

TABLE 6-1
RESULTS OF FLY EMERGENCE STUDIES

Dates of Study	Location	Specific Fill Type	Number of Traps	Total Flies	Flies/ Trap/Day
10/18/72-11/7/72	Oceanside	With sludge and cover soil	4	0	0
		Without sludge and cover soil	4	0	0
11/30/72-12/14/72	Oceanside	With sludge and cover soil	4	0	0
		Without sludge and cover soil	4	0	0
8/10/73-8/27/73	Oceanside	With sludge and cover soil	4	31	0.97
		Without sludge and cover soil	4	31	0.97
10/15/73-11/2/73	Oceanside	With sludge and without cover soil	4	116	1.53
		With sludge and cover soil	4	0	0
11/14/73-12/7/73	Oceanside	With sludge and without cover soil	4	60	0.62
		Without sludge and cover soil	4	122	1.27
6/25/73-7/7/73	Oceanside	With sludge and cover soil	4	30	0.58
		Without sludge and with cover soil	4	16	0.31
4/30/74-5/22/74	St. Paul	Baled with cover soil	5	165	1.43
		Baled without cover soil	5	178	1.55
5/28/74-6/22/74	St. Paul	Baled with cover soil	5	76	0.73
		Baled without cover soil	5	355	3.41

- Generally, cover soil reduced fly emergence.
- The amount of cover soil necessary to reduce flies significantly varied with seasonal changes.
- Baling alone did not appear to inhibit fly emergence.

Environmental advantages associated with balefills as compared to conventional landfills appear to be reduced numbers of birds; reduced surface area at the balefill; increased density of the solid waste to be disposed (on the order of 1.5 times--see Table 9-22); and reduction in the volume of dirt needed at the fill (on the order of 90 percent) due to reduced surface area requiring cover soil.

SECTION 7
TIME AND METHOD STUDY

A. Purpose and Scope

This section discusses the time performance of the St. Paul baling plant, transport net, and balefill. Since the time analysis is detailed and extensive, the more comprehensive work on operating times and all of the work on human factors have been placed in Appendix E. Results and evaluations are presented in this section.

This analysis of time performance uses simultaneous observations of the overall system of individual men and machines. Attaching time values to machine states that are disjointed in time is a powerful method of description. This information describes the use made of men and machines. While individual performances are not enough to describe system performance, the effect of the defined states is to represent the system as a network of operating states. This network structure is the basis for the time and method study.

Human factors greatly influence plant performance. Factors include operator location and visual perspective, instrument and control design and location, and required force and precision of operator movements. These factors are identified and evaluated in Appendix E.

Plant data for time and methods analysis was obtained as follows during a five day plant monitoring period and over a one year study period:

1. Stopwatch Timing. Time studies of the baling process were completed for 30 minute periods twice daily, with revisions on three days due to plant operating variations. Two men entered continuous time data on operations Activity Charts 1-A and 1-B (as shown in Appendix A), simultaneously covering all operations performed during solid waste processing.

2. Video Tape Records. Daily video tape recordings were made of each of the three labor positions on the production line: the gateman, loader operator and control tower baler operator. The video tapes were analyzed by task time and motion measurement to define human factors.

3. Bale Landfill Equipment Timing. Ralph Stone and Company personnel in St. Paul timed the balefill forklift almost weekly over the year of the balefill study.

B. Plant Performance

1. Machines. Within the accuracy of the observed measurements, the plant production machines formed an integrated and compatible network of operations. Thus, when the plant

was in steady-state operating condition, all machines showed high run percentages and low interference.

The utilization values listed in Figure 7-1 show that the baler had the lowest flow rate: all other machines waited on the baler. In a sequence of operations such as the baling plant, all other machines should properly feed the major machine without slowing the process rate. Thus, the plant could operate at a maximum rate equal to the baler rate.

The interference values in Table 7-1 show that the loader and conveyor both interfered with the baler. To have less important machines slowing the baler (and plant) cycle rate is a costly condition. Observation of the baler plant could explain these interferences. First, the loader fed the conveyor easily for a long period of time, until the loader operator stopped for personal reasons. Then the conveyor was not fed for approximately 10 minutes, and the plant was idle until the loader operator returns. Even if the conveyor was empty for a 6-meter stretch, it took one minute for the conveyor to move that 6 meters. Secondly, the loader operator also affected conveyor/baler interference by the height of the solid waste he piled on the conveyor. Thus, the time to load one charge onto the scale would have been less than one minute or more than two minutes depending on the conveyor's load. Thus, the conveyor can keep up with the baler sometimes and then fall behind at other times. The loader operator affects this balance.

The conveyor was observed to stop a number of times while loading the platen. The occurrence of these stops varied with each load cycle. If the delay was short, it was included in the time to load, causing the baler to wait for the conveyor at a later time. If the delay was long, the time was included directly in the total time the baler waited for the conveyor. Intermittent stopping was an unresolved problem with the present conveyor.

2. Personnel. The work-station positions varied and were often poorly coordinated. Indications of this were the high percentage of labor idle time; the lack of assistance for the gateman during periods of peak vehicle arrivals; the lack of a replacement for the loader operator and control tower operator; incomplete coverage of records and maintenance responsibilities; and the many people working in the plant, particularly on the day shift. The percent idle time was so high that employee boredom was expected, thus further degrading labor productivity. Common percent idle times in industry are between 10 and 25 percent. Idle time is only one parameter of inefficiency. The factors actually lying at the root of the problem are job descriptions and defined responsibilities.

Each man on a machine in the production line needs a backup in order for him to stop for a time without crippling the plant. Thus, a maintenance man or other non-line man should have been available to fill in for the gateman, loader operator, and control tower operator. This would have improved the baling production rate by a minimum of 5 percent at St. Paul.

The responsibilities of the gateman required one man to process all trucks that entered the plant. This was impossible when two trucks entered simultaneously. Trucks could enter

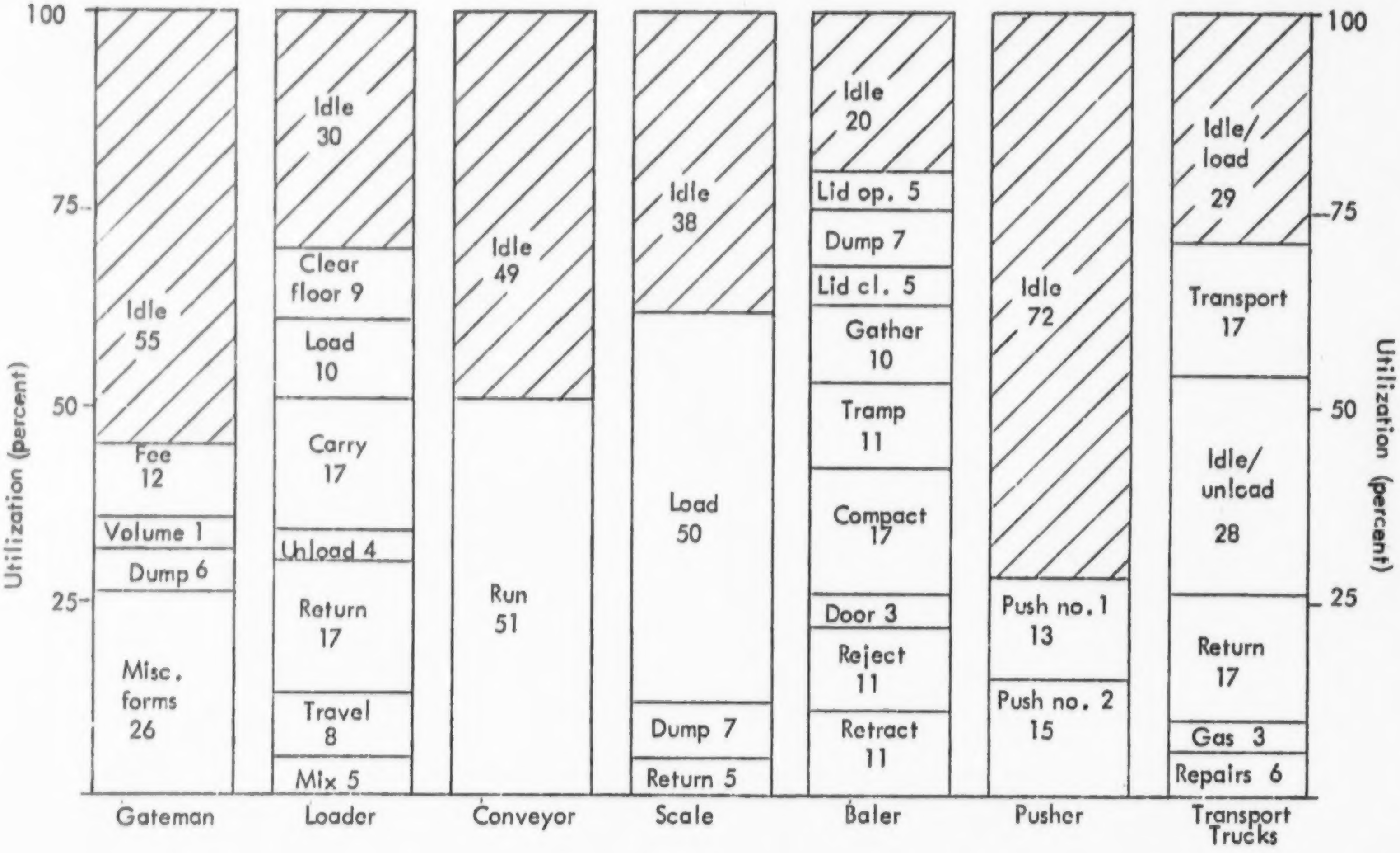


FIGURE 7-1
STATE UTILIZATION BY MACHINE
(IN PERCENT)

TABLE 7-1
MACHINE INTERFERENCE BY MACHINE

Causing Interference / Interfered with	Gateman	Loader	Conveyor	Scale	Baler	Pusher	Transport
Gateman	----	——	——	——	——	——	——
Loader	10[b]/33	----	——	——	——	——	——
Conveyor	——	4/8	----	11/22	18/37	——	——
Scale	——	3/8	17/45	----	18/47	——	——
Baler	——	3/15	13/65		----	——	——
Pusher	——	3[a]/4	13[a]/18		56/78	----	——
Transport	——	1[a]/3	4[a]/14	24/83	——	----	——

[a] Number follows from previous step.

[b] Estimated from videotape /based on his waiting for trucks and gateman.

$\boxed{X/Y}$

$$X = \frac{\text{Average idle time per cycle due to interfering machine}}{\text{Average cycle time of machine being interfered with}}$$

$$Y = \frac{\text{Average idle time per cycle due to interfering machine}}{\text{Average total idle time per cycle of machine being interfered with}}$$

unannounced, creating a traffic jam and safety hazard. The loader was slowed and threatened by this confusion. The degree of responsibility of the loader operator in avoiding collisions was very great. The loader operator took total responsibility for avoiding collisions with collection trucks. In time, a human error could prove costly.

The total number of employees on the first shift was eleven. Six men worked the second shift. Only the gateman, loader operator, two truck drivers, and control tower operator were production workers. The gateman was not critical to maintaining bale production, and the difference between the four required men and the eleven actual men was very large. Redefining work tasks and responsibilities would have improved the labor productivity and reduced the labor requirement and associated cost.

3. Incoming Waste Handling. The plant's method of handling incoming solid waste needed review. It was inconsistently performed and minimally productive. The defined tasks and subtasks of the gateman, the floor layout and front doors, and the method of working the floor pile contributed to this difficulty.

In order to evaluate alternative methods, consider the steps of handling incoming solid waste as a network of operations: 1) charge a fee, 2) dump the waste, 3) mix the waste, 4) reject some items, 5) recycle some items, 6) load the conveyor, and 7) convey.

One source of the delays and the potential danger of collision was the unscheduled arrival of the collection trucks. Figure 7-2 illustrates the pattern of arrival of solid waste in volume terms. From one to two in the afternoon more than twice the average hourly intake occurred. In the early morning and late afternoon, few trucks arrived. For part of the day a gateman was idle; for part of the day two gatemen were needed to fully handle all incoming trucks without delay. The loader vehicle had to wait when 3 or more trucks arrived, especially when the floor was already full. Thus, the condition of a full floor and many incoming trucks slowed the loader even more. Figures 7-3 and 7-4 show the pattern of solid waste volume on the floor, using the arrival pattern of Figure 7-2 and using different production rates for the baler.

With a faster baler, a second difficulty occurs due to the unscheduled arrival of incoming trucks. The plant can run out of solid waste to bale at times during the day. Yet at other times a large section of floor will be covered with solid waste recently brought in. The fast 90-second cycle aggravates this problem; it can bale all the solid waste in eight hours, but if more waste is brought in, it will arrive at the time of day when the floor is most filled. Thus, solid waste arrivals should be under much tighter control; for example, transfer stations would allow scheduled shipments to the plant. A larger floor would provide the space to store more solid waste, although minimizing floor space is a desirable goal to reduce cost. The gateman would be eliminated by using transfer stations, and a larger floor would thus not be needed.

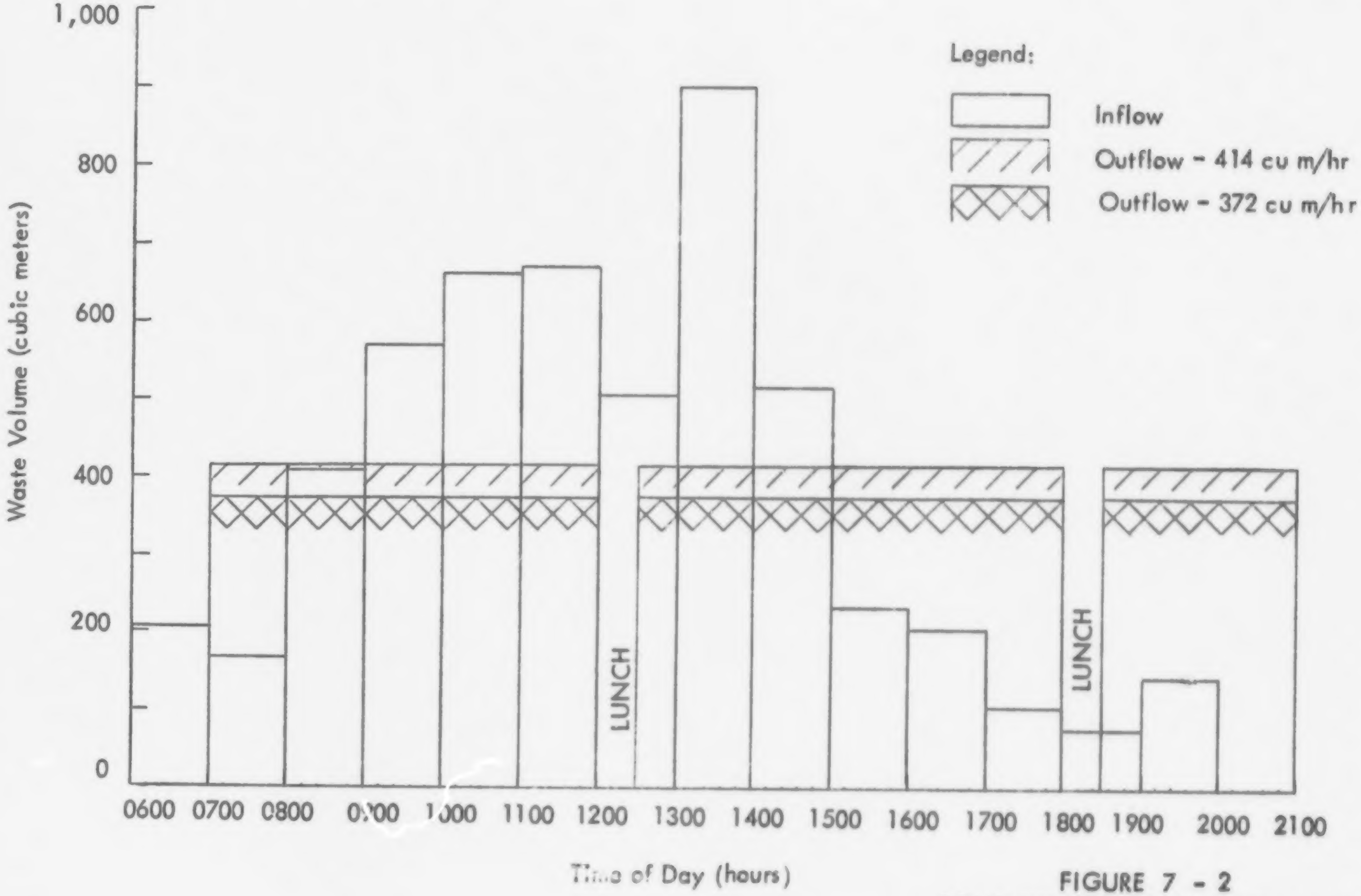


FIGURE 7 - 2
SOLID WASTE VOLUME FLOW RATE
INFLOW AND OUTFLOW

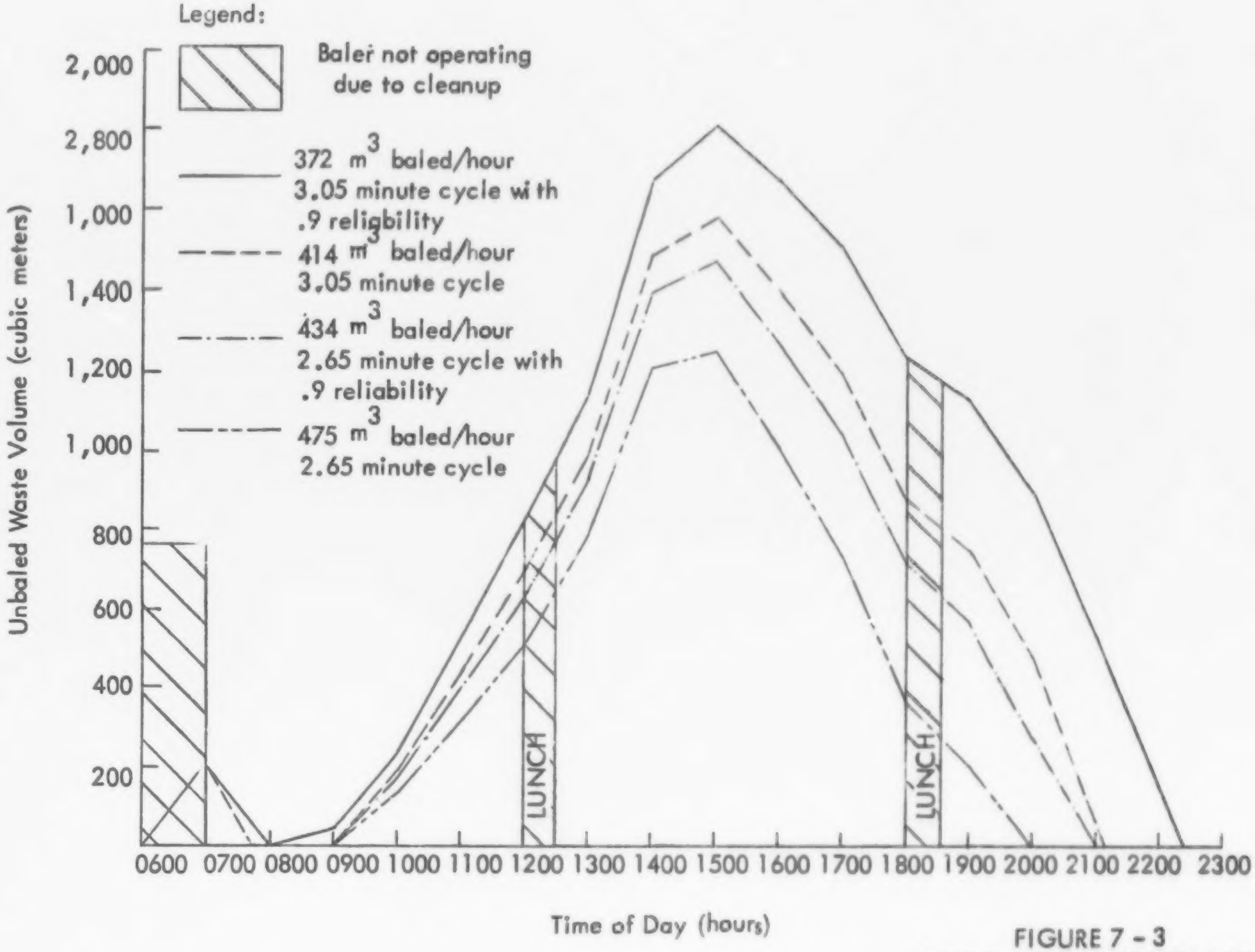


FIGURE 7 - 3
CUMULATIVE AVERAGE SOLID WASTE VOLUME FOR EXISTING (137 SEC CYCLE) ST. PAUL BALER

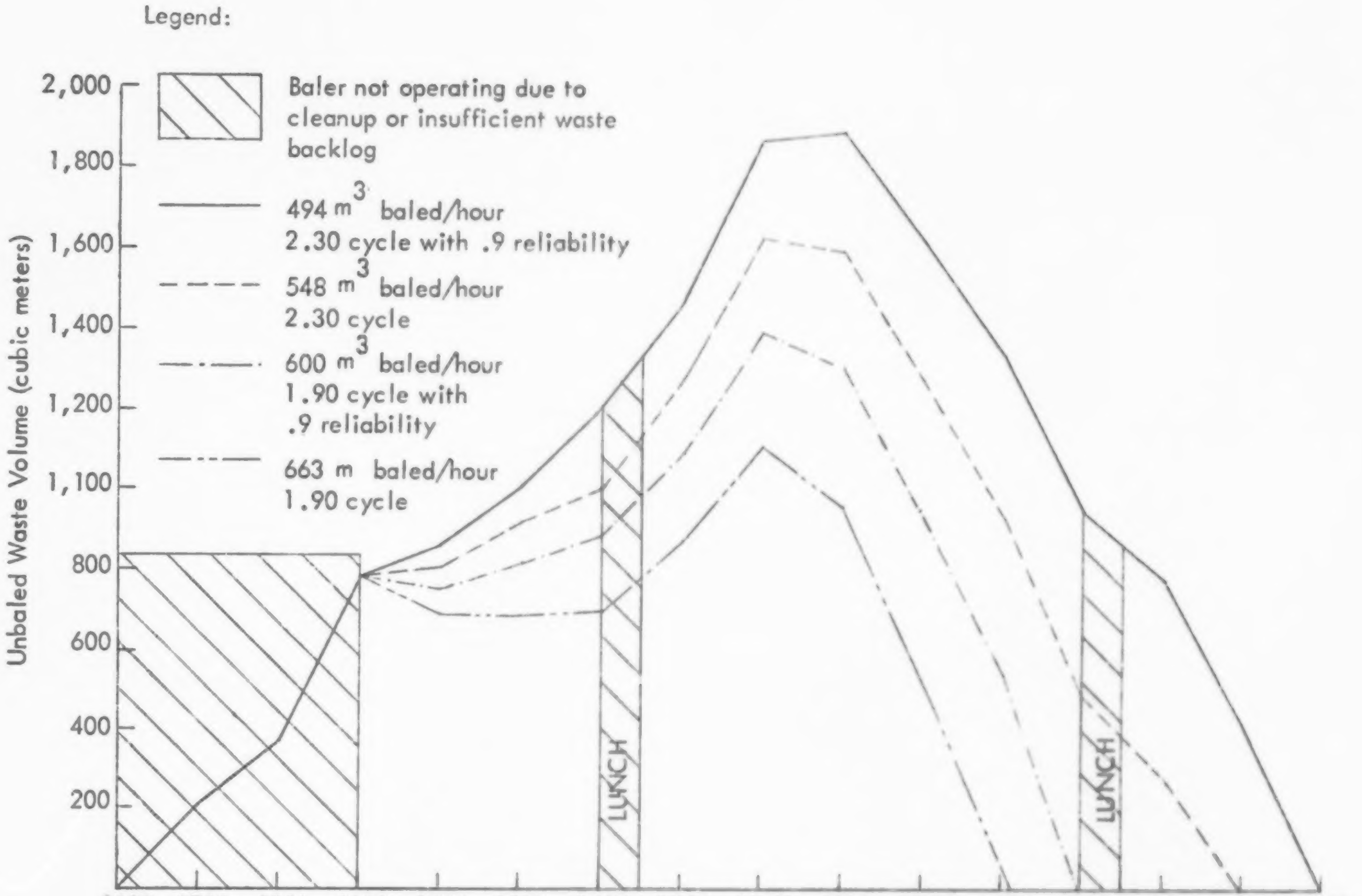


FIGURE 7-4
CUMULATIVE AVERAGE SOLID WASTE VOLUME
ON BALING PLANT FLOOR
FOR 90-SEC CYCLE BALER
WITH ST. PAUL WASTE INFLOW

Depending on the way incoming waste is handled, the remaining sequence of operations on incoming waste is subject to improvement. An overhead rail crane could rapidly and cheaply handle heavy and bulky materials; perhaps the loader and conveyor could have been replaced by a crane. The present hand-sorting method of recycling was satisfactory at the relatively high price prevailing for salvaged corrugated. Mechanical sorting of corrugated would require a shredder and air classifier which would necessitate a complete reclamation plant with magnetic separation of ferrous materials. A baling plant built in Cobb County, Georgia and operating since mid-1974 incorporates a complete reclamation system.

4. Concept Performance. The newest American Hoist and Derrick Company baler was designed for a 90-second cycle, excluding the idle and dump operations. This means that a plant can have under a 1.9 minute baling production cycle using 0.20 minutes for both dump and idle. The other machines in the sequence would need to have increased operating rates, and some machines may need to be redesigned or replaced.

The conveyor and scale were time-costly and troublesome. Thus, this pair of operations might best be achieved using different methods.

The pusher and transport net performed dependably. Under the more rapid bale production rate, the transports might be a problem due to traffic delays. As cycle time decreases, more trucks might be needed depending upon the maximum permitted by state vehicle load limits.

The behavior of the loader was less obvious. Using present data, the loader could not load the new baler fast enough. But under improved solid waste handling conditions associated with a transfer station or new floor layout, perhaps one loader would be fast enough.

Any new baling plant should have a conveyor that is level for its total length, if feasible. The loader can then load the conveyor along its total length, thus avoiding costly delays due to an empty conveyor. Also, excess travel time from the solid waste stockpile to a single conveyor loading point would be eliminated. The conveyor must be jam-free; otherwise, high labor activity and cycle delays are inevitable. A gravity chute, a faster scale platen, and a mechanical mixer and loader are possible innovations.

The number of employees should be kept to a minimum. Perhaps six men are needed per shift: a foreman-control tower operator, a loader operator, two truck drivers, a leadman-mechanic, and a maintenance man. The control tower operator should be in charge of the shift due to the qualities required in his position and the overview of his location. The mechanic and maintenance men should be able to fill in other positions when necessary. The recycling of solid waste is a relatively new concept. The benefits of recycling will probably continue to grow in the future. A baling plant may be an economical place to recycle many items such as cardboard, paper, aluminum, steel, tin, and glass. For a baling plant performing recycling, advertising for and accepting or purchasing sorted solid waste may be as profitable as the baling operation.

In order to perform sorting, mechanical and electrical methods are needed, since labor cost compared to productivity is prohibitive. Sorting may be accomplished in partial stages during regular handling processes of dumping, storing, mixing, and conveying. Differences in size, shape, weight, and denisty may be employed to initially separate items.

5. Alternatives in Design of a 90-Second Plant. A new baler would significantly increase the productivity of a plant to as much as 160 percent of past production. This provides an impetus to develop high speed equipment for bulk handling and sorting of solid waste. The reduced network in Table 7-2 is a basic model by which to compare various alternative systems.

Transfer stations are a likely part of baled solid waste system. A system of transfer stations can reduce travel and dump times for collection crews, eliminate the cost of handling the trucks at the baling plant, and will premix the solid waste. The drawbacks are the investment in property and special pits and the increased time that waste is in storage. Train cars can be used: collection trucks can dump directly onto the open tops of hopper cars. Trains can transfer the solid waste from remote areas. Bottom-loading, high-wall cars can be unloaded on a fixed schedule.

A gravity-feed conveyor chute would eliminate labor and power requirements in waste handling. Thus a chute may be aimed directly onto the scale. A power ram would be necessary to push the waste down the chute at a predetermined rate to provide control of the weight of waste in each bale. A problem might still be encountered, however, in controlling the quantity of waste in each bale charge since the charge on the scale may reach the desired weight while more waste is coming down the chute.

Mechanical sorters now on the market sort by density, size, weight, color, ferromagnetism, and strength. These sorters don't collect 100 percent of the desired items, but hand-sorting also does not approach this figure. Actually, sorting between 25 and 80 percent of such items as steel, aluminum, glass, cardboard, and paper will suffice to recycle large amounts where markets exist.

A combination of conveyor and sorter would save time and money. The state-of-the-art uses magnetic separation somewhere in the sorting. Tentative methods use density dispersion, air classification, magnetic and eddy current separation of ferrous and nonferrous metals, photoelectric color identification, shredding, and bouancy. A larger baling plant with high volume through-put can meet the investment costs required for sorting machines. Perhaps one fundamental justification for baled solid waste systems is the convenience of recycling at the baling plant.

The scale-baler-pusher for the 90-second baler are basically the same as the St. Paul model. The small detail of providing a hydraulic lift to raise the bale discharge

TABLE 7-2

REDUCED BALED SOLID WASTE NETWORK

Operation	Cycles Per Baler Cycle	Average Process Times (min.) Per Bale	Average Process Times (min.) Per 1,000 Kilograms
(1) Dump on Floor	-	2.40[a]	1.90
(2) Store/Mix	-	-	-
(3) Load Conveyor	2.8	1.50	1.20
(4) Convey	1	3.00	2.35
(5) Measure Charge	1	0.05	0.04
(6) Bale	1	3.05	2.40
(7) Load Trailer	0.5	3.15	2.50
(8) Wait on Trailer	0.07	21.0	16.5
(9) Transport	-	2.0	1.6
(10) Wait on Trailer	-	25.0	19.7
(11) Stack	1	1.5	1.2
(12) Cover	-	-	-

[a] Estimated from video tapes.

platform over the truck bed will hopefully be resolved. The control tower, pump room, and utilities are unchanged except for adding another pump.

The 90-second plant would be able to complete the solid waste processing by loading bales two at a time into train cars for long-distance removal. A justification for the baled solid waste system is inexpensive transportation costs. The destination of the solid waste bales would be a remote balefill. Perhaps many cities will use a single fill. A fundamental justification for baling solid waste is the reduction in volume and lack of settlement at the fill and the ease of reclaiming the waste at future dates. The bales may be used as engineering materials, but little research has been completed on bales as foundation materials over a long time period.

C. Ability, Reliability, and Accessibility

Knowing the ability, reliability, and accessibility of plant components provides information on different facets of productivity and indicates anomalies and necessary improvements. Management can use this information for planning production schedules and calculating design parameters in general (such as required storage space).

7. Ability. Ability refers to the probability that a system is producing at a stated rate; for a baling plant, the hourly average number of bales turned out (over an eight hour shift) is the rate most appropriately indicating ability. Figure 7-5 presents the probability distributions for ability during two separate study periods.

The two distributions are sufficiently different in mean value and shape to indicate changes in baling plant equipment conditions. Unfortunately, the causes cannot be determined by the ability distributions. It is known that two factors changed between observation periods: the baler's lining was replaced; and the production data was made to include all production on the second shift. The increased ability, therefore, could have been a function of improvements with the new liner, higher second shift productivity, or some other factor.

The later ability distribution is superior due to its higher mean production rate and its much smaller variation about the mean production rate. The reason for two peaks is not known, but the rise of almost forty data points, producing an otherwise smooth curve, strongly indicates the existence of two peaks. Under the more recent conditions, management could expect to produce between 19.5 and 23.5 bales per hour during production time, with 64.8 percent probability of baling at between 22.0 and 22.49 bales per hour. Notice that labor management conditions have a strong effect on the shape of the ability curve of a specific plant.

The effects of moisture content and automatic or manual control on bale production also requires investigation. During the five day plant study, data were gathered on average production rates under varying conditions. Table 7-3 summarizes the results. No measureable difference exists between automatic and manual production rates. The longer production

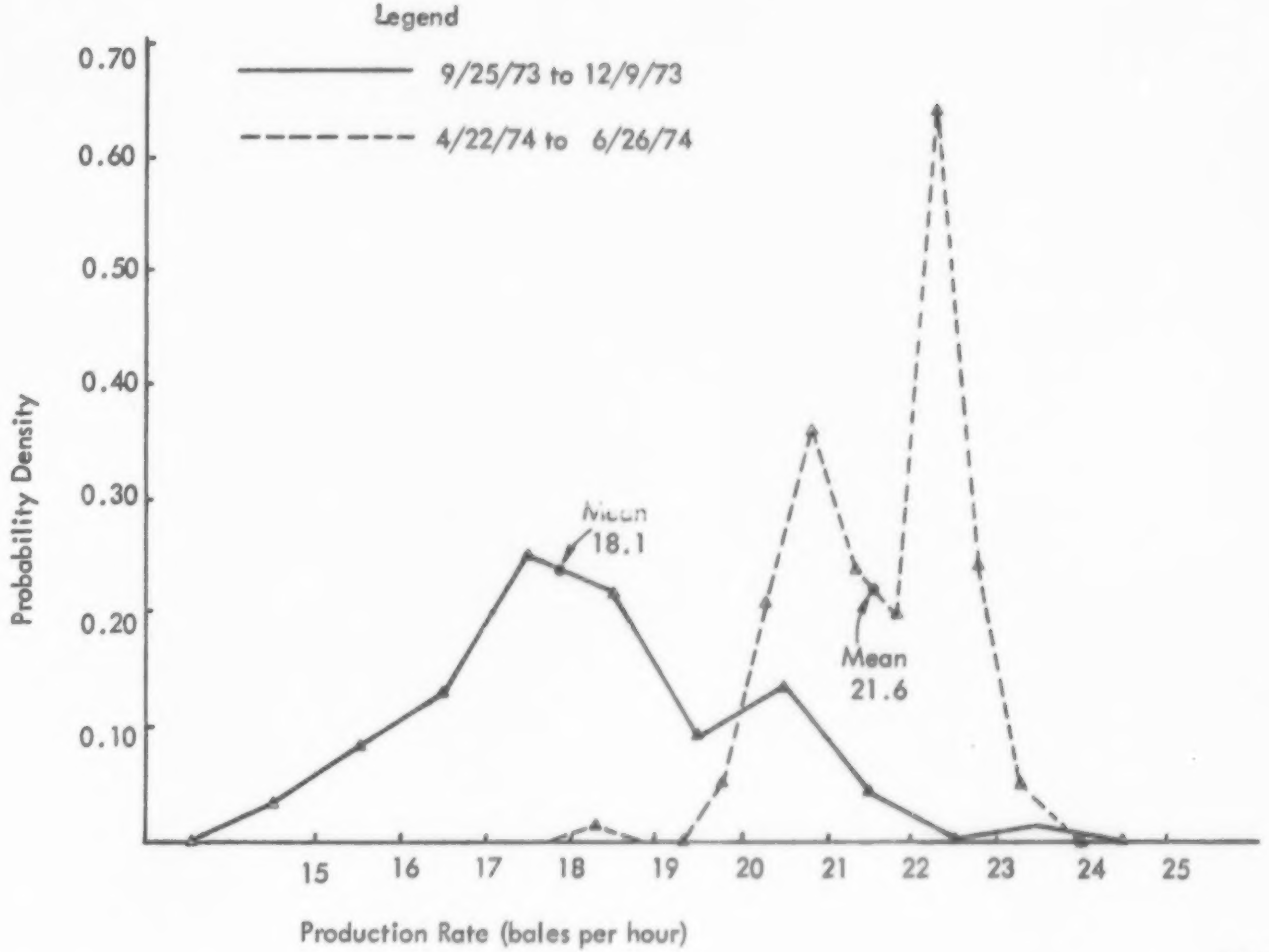


FIGURE 7-5
ABILITY DENSITY CURVE

TABLE 7- 3

BALING RATES UNDER MEASURED CONDITIONS

Group Date 1973	Baling Cycle (min.)	Bales per hour	Conditions
1 9-20/21	2.80	21.4	Automatic Dry Waste
2 9-24/28	3.15	19.0	Automatic Wet Waste
3 9-25	2.80	21.4	Manual Moist Waste
4 9-24/26	3.30	18.2	Manual Wet Waste
Total	3.05	19.7	Summary

times in groups 3 and 4 were mostly due to unrelated difficulties with the conveyor and loader. Thus, the mode of control has minimal effect when a skilled operator is in control, and higher moisture contents will slightly lower the ability to produce, but not enough to require special consideration.

2. Reliability. Reliability refers to the probability that a system will operate any given percentage of the scheduled operating time. For the baler, an appropriate reliability measure is the probability of operating a given number of hours per 8 hour shift. Figure 7-6 presents reliability curves for two different time periods and their average.

The difference in reliability between the two time periods is not large. The more recent period has a better reliability curve but has the same basic shape as the previous period. The average curve is probably the best for application since it uses all available data.

The shape of the curve is typical of most systems. The basic shape indicates no dominant pattern of breakdown, as might appear if a specific part continually broke and was repaired repeatedly within a shift. For the earlier 1973 time period (see Figure 7-6), the peak at 7 hours is typical of a specific reliability problem, but it disappears in the later 1974 time period. The minor peak at 5 hours indicates a loose pattern of breakdowns and repairs taking 3 hours to complete.

3. Accessibility. Accessibility refers to the maximum time per operating cycle that the system can be scheduled for operation; the remaining time is dedicated to scheduled, periodic maintenance. For the baling plant, the basic cycle is the 24 hour day. Longer cycles (weeks, months, etc.) are of minor importance and must be considered only when the plant is scheduled three shifts, seven days a week.

On a 24-hour cycle, the baling plant can run 23 hours if lunches are staggered and each man has a replacement during his lunch period. If the plant shuts down for lunch, then only 21.5 hours can be scheduled per day. At least one hour per day is needed to remove waste from between machine parts. Most likely, any municipal baling plant will operate one to two full shifts. Thus, the time lost to periodic maintenance and lunches does not restrict production time.

4. Time Performance. Bale plant performance, in terms of bales per shift, is presented in Figure 7-7. These production curves were determined directly from the sampled production days, but they could have been found by the mathematical convolution of the ability and reliability curves. These curves are useful when designing system parameters such as waste storage space and landfill equipment requirements.

A significant difference exists between the production curves for the earlier and later periods as seen by the respective means of 119 and 142 bales per shift. This difference could be expected from the difference in ability and reliability curves, but the physical reasons are buried in the complex interactions of the plant. The existance of distinct

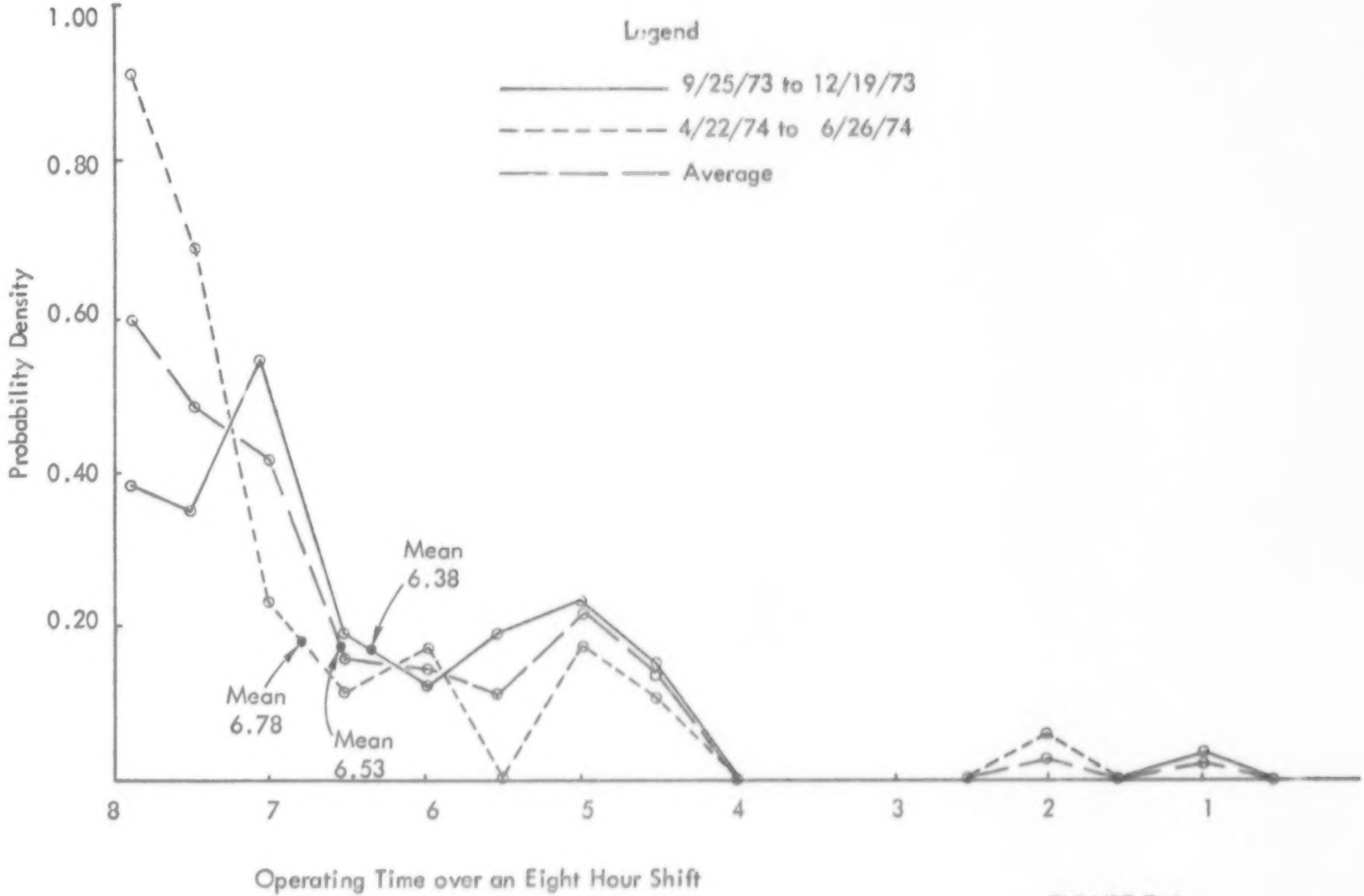


FIGURE 7-6
RELIABILITY DENSITY CURVE

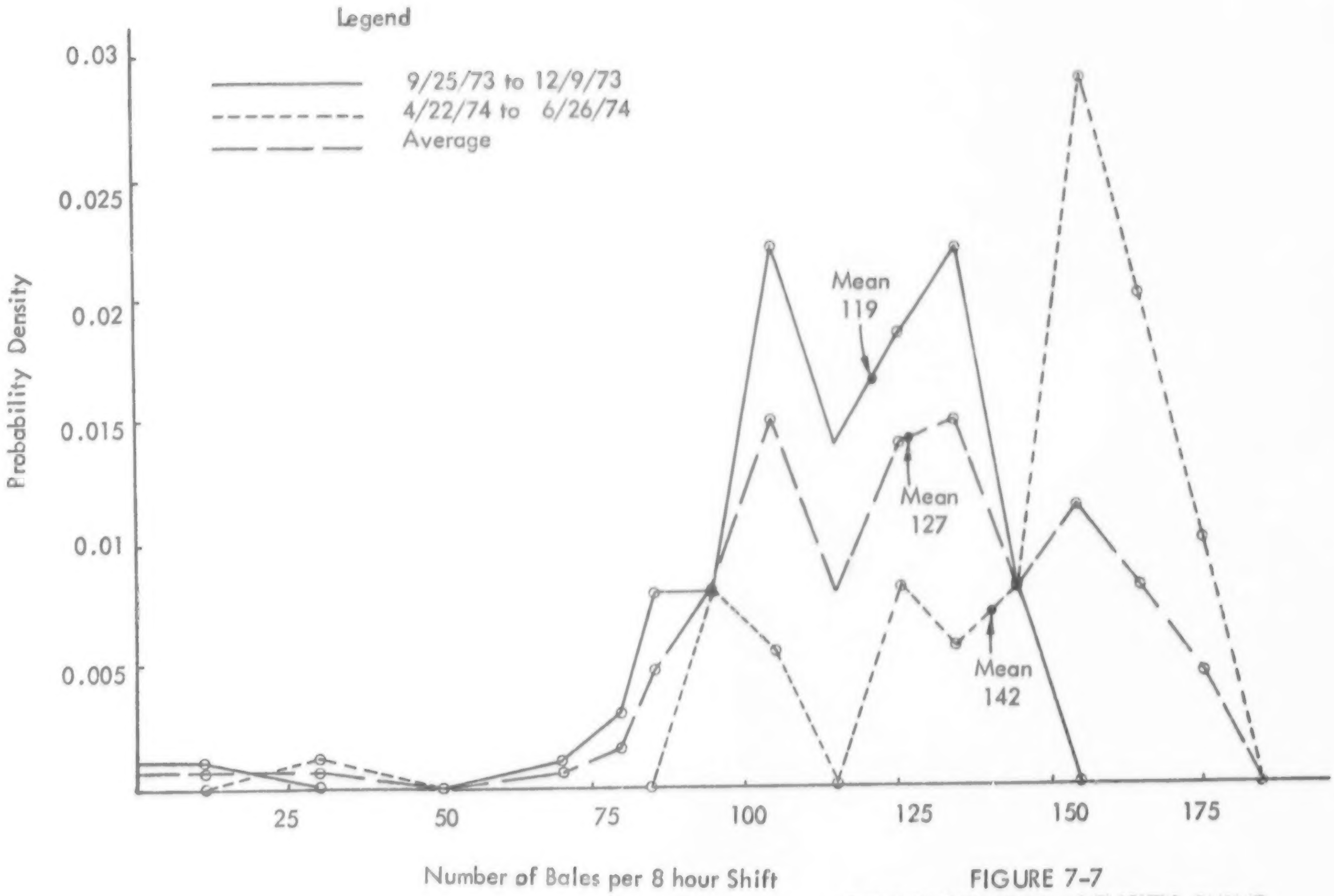


FIGURE 7-7
BALE PRODUCTION DENSITY CURVE

peaks is not typical since a bell-shaped curve is the usual distribution configuration. For production planning purposes, however, a normal distribution with given mean and variance can be substituted.

Ability, reliability, and accessibility curves are the basis of any probabilistic description of the baler plant. This can be seen by their possible use in constructing a shift production curve. This information can be used both in evaluating the St. Paul plant and planning other plants.

SECTION 8

MAINTENANCE STUDY

Planned maintenance is a program of scheduled maintenance as opposed to maintenance occurring for random emergency repairs. Checklists of cleaning, lubricating, inspecting, adjusting, and replacing parts are the working tools of such a planned program. Accurate and accessible records of downtimes, broken parts, maintenance labor times, and causes of trouble are the solid foundation on which to base this program.

A planned inventory is a stock of critical parts on immediate hand with crucial subassemblies preassembled, ready to be installed on the machine. Critical parts are those that break often, are scarce, have close tolerance, require special tools and skills to install, or take a long time to assemble. A planned inventory reduces procurement and repair time and related cost, thus achieving higher productivity at lower overall maintenance cost.

A manufacturer's policy on service and parts is one key to the productivity of the equipment he makes. This section outlines the policy and practice of American Hoist and Derrick Company, with regard to maintenance and parts inventories.

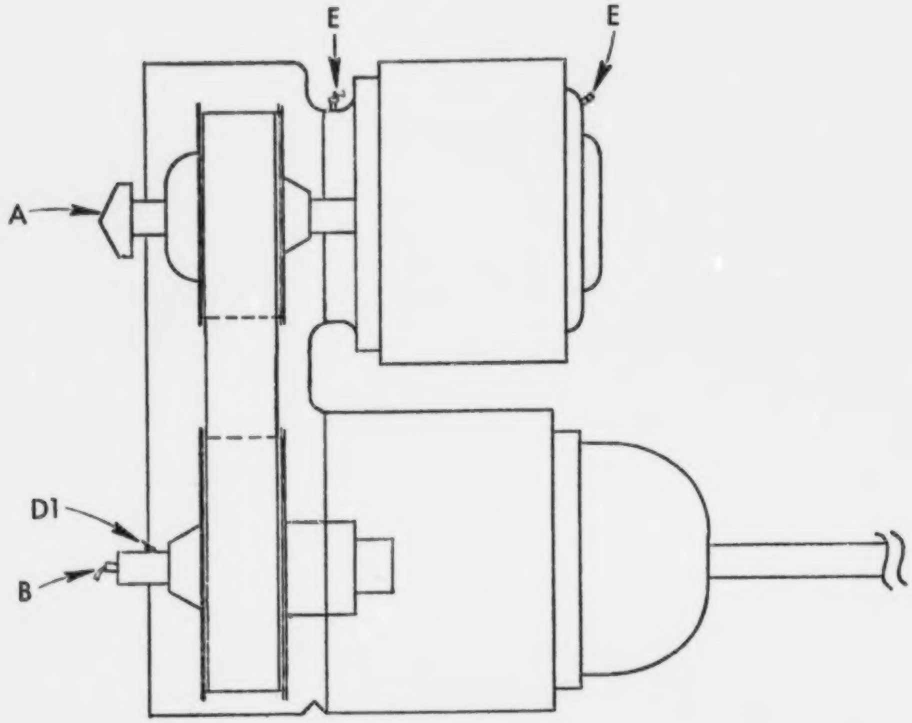
A. Planned Maintenance.

Planned maintenance included the whole baling system, but this section concentrates on the major items of equipment. In the plant these consisted of the baler, scale, conveyor, and front end loader. The transport net consisted of four transport trucks, and the balefill had a forklift and a front end loader.

1. Baler, Scale, Conveyor, and Loader. Each morning a pre-startup inspection of the baler, scale, conveyor, and loader was performed. The baler was cycled without a charge in order to warm up the oil. Lubrication points for the conveyor are illustrated in Figure 8-1. The equipment was run for between four and six hours, after which the area behind the gathering ram and the base of the baler were cleaned of litter. The higher the moisture and vegetation content of incoming waste, the more frequently this cleaning was needed. Once each day the conveyor pit was cleaned of litter.

At the St. Paul baling plant the hour between 6 and 7 a.m. characteristically was reserved for the daily inspection and conveyor pit cleaning during the five day plant study. Previously a third shift performed the cleanup. The baler was cleaned as needed, and any idle men were assigned cleaning duties. Table 8-1 lists the daily inspection tasks. Note that the conveyor was cleaned during lunch break on the first shift, and frequently during the second-shift lunch break.

Other plant maintenance was performed as scheduled. Tables 8-2 and 8-3 present the maintenance performed less frequently. A maintenance schedule is half of the planned maintenance program at the baling plant. The other half is a file of maintenance records.



Legend:

A = Pulley adjustable sliding disk, driver.
B = Pulley adjustable sliding disk, follower.
D1 = Motor drive variable shaft bearing.
E = Motor bearings.

FIGURE 8-1
LUBRICATION POINTS OF VARIABLE
SPEED CONVEYOR DRIVE

TABLE 8-1
DAILY MAINTENANCE IN BALING PLANT

A. Baler and Scale

1. Clean behind rams of baler and pusher. Do every four to six hours of operation.
2. Check bolts for wear and tightness.
3. Check oil level in tank, making sure it is from 5 to 15 cm (2-6 in.) from top of the gage.
4. Check oil temperature. Use oil heaters overnight in cold weather. Never run pumps if oil is below 60°F.
5. Start motors from power room control station and check motors and pumps for ease of turning.
6. Check pumps, lines, and baler for leaks.
7. Check and lubricate push ram guides.
8. Check push ram cylinder mounting and rod clevis pin.
9. Check baler cycle for several runs. Run 8 to 10 cycles in cold weather, without a charge.
10. Clean limit switches of foreign materials. Make sure the limit switch arms move freely.
11. Zero out load cells. Allow at least 10 minutes for the electronic equipment to warm up.
12. Check the tie-rods for levelness.

B. Conveyor

1. Clean conveyor pit.
2. Check bolts for wear and tightness.
3. Check drive chain and wheels for wear and tension.
4. Check conveyor belt for snags and jams.

C. Bobcat Loader

1. Check fuel and crankcase oil levels.
2. Check radiator water level.
3. Start and warm up engine.
4. Check hydraulic hoses and fittings for wear and tightness.
5. Check bolts for wear and tightness.
6. Lubricate as manufacturer recommends.

TABLE 8-2
WEEKLY MAINTENANCE IN BALING PLANT

A. Baler and Scale
  1. Check and clean screens in oil reservoir.
  2. When oil is cool, check hydraulic pressure adjustments and set per hydraulic circuit specifications.
  3. Lubricate motor to pump couplings.
  4. Lubricate mounting blocks for shifter cylinders.
  5. Lubricate baler lid cylinder trunnions.
  6. Check hydraulic hoses and fittings for wear, tightness, and leaks.
  7. Check wear plates for missing bolts, wear, or damage.
  8. Check bolt flanges of all cylinder rods.
  9. Check all bolts for wear and tightness.

B. Conveyor
  1. Check and adjust chain slack and take-ups.
  2. With conveyor empty, check skirts for damage, especially the lower lips of the conveyor.
  3. Check rail and rail fasteners for wear and tightness.
  4. Lubricate the pillow blocks and takeup bearings.

C. Bobcat Loader
  1. Check tire pressure.
  2. Check accessories.
  3. Clean windows and cab.
  4. Lubricate as manufacturer suggests.

TABLE 8-3
LONG-TERM MAINTENANCE IN BALING PLANT

A. Baler and Scale

Six-Months:
1. Drain oil from reservoir and clear tank.
2. Filter or replace the 1800 gallons of hydraulic oil.

Year:
1. Have an electrician to lubricate all motors.
2. Check wiring, switches, and fuses in the electrical system.

B. Conveyor

Monthly:
1. Lubricate the sliding disks of the variable speed drive at points A and B in Figure 8-1.

Two-Months:
1. Check oil level in the motordrive reducer.
2. Open reducer oil vent if clogged.

Six-Months:
1. Lubricate motor bearings at point E, and motordrive variable shaft bearings at point D1 of Figure 8-1.
2. Drain and flush reducer housing.
3. Refill with fresh oil.
4. Check belt of variable speed drive.

C. Bobcat Loader
1. Change crankcase oil and oil filter, air cleaner, hydraulic oil as recommended.
2. Check transmission oil level every two months.
3. Check rear axle oil level every six months.
4. Tuneup as recommended.

It is not enough to design a maintenance schedule. A record of maintenance performed is vital; perhaps a log or checklists would be sufficient. A record of downtimes, replaced parts and cost, maintenance labor time and cost, and causes of the trouble are the information bases for evaluating current production and maintenance procedures. The control tower operator could have an operating log including startup times, breakdown times and causes, and shutdown times. He could also record bale production. The data on parts and labor would be the plant supervisor's responsibility.

The maintenance history provides a basis for evaluating present maintenance and scheduling new maintenance based on production and past maintenance time and costs. The maintenance history also provides a design parameter for incoming waste storage area requirements.

2. Transport Trucks. Each morning a pre-starting inspection of the transport trucks was performed. Then the trucks ran all day with stops for gas and minor repairs. Table 8-4 lists the daily and monthly truck maintenance. Included in the maintenance is the sweeping of the empty truck beds by the balefill equipment operator to avoid littering the road. This was performed every trip after bales are unloaded from each truck.

The truck drivers kept a log of their activities. This log contained information on breakdown times and causes. Depending on the maintenance program, a privately contracted company doing the maintenance or the plant foreman recorded parts and labor costs.

The St. Paul plant contracted truck maintenance out to a private firm.

3. Forklift Wheel Loader. Each morning prior to startup, an inspection was performed. Then the lift ran all day with stops for gas. The balefill had limited fuel storage for this purpose. Table 8-5 lists the planned maintenance for the lift. The balefill operator should be keeping a log of his operations including downtimes and replaced parts. Downtimes, replaced parts and their cost, and labor time and cost are useful as historical data for designing new systems or improving existing operations.

B. Planned Inventory.

A planned inventory is a stock of replacement parts stored on the site, with some assemblies preassembled. The basis for a planned inventory is the maintenance history of the equipment and knowledge of critical parts that are scarce or time-expensive to reassemble.

TABLE 8-4
TRANSPORT NET MAINTENANCE

Transport trucks

Daily:

1. Check tires, trailer hitch and connections, curtain, and outside accessories.
2. Check oil, water, and windshield fluid.
3. Start engine and let warm up.[a]
4. Check brakes.
5. Clean off truck trailer bed at balefill, every trip after unloading bales.

Monthly:

1. Change air cleaner.
2. Check brake fluid level.
3. Check steering travel.

Two-months:

1. Change oil.

---

[a] Common practice is to leave the truck engines running to keep them warm and at the best operating temperature.

TABLE 8-5
BALEFILL EQUIPMENT MAINTENANCE

Forklift Wheel Loader

Daily:

1. Check fuel and crankcase oil levels.
2. Check radiator water level.
3. Start and warm-up engine.
4. Check hydraulic hoses and fittings for wear and tightness.
5. Check bolts for wear and tightness.
6. Lubricate as manufacturer recommends.

Weekly:

1. Check tire pressure.
2. Check accessories.
3. Clean windows and cab.
4. Lubricate as manufacturer suggests.

As Recommended:

1. Change crankcase oil and oil filter, air cleaner, hydraulic oil as recommended by manufacturer.
2. Check transmission oil level every two months.
3. Check rear axle oil level every six months.
4. Tuneup as recommended by manufacturer.

American Solid Waste Systems provided a recommended spare parts list based on their experience in scrap metal baling in St. Paul and elsewhere. From Table C-10, the total cost of the recommended inventory (just under $14,000) makes the investment worthwhile when time savings are calculated.

C. Service and Parts Policy.

Harris Shear and Press, Inc., claimed to mail any baler part within 24 hours after receiving an order. This service and an investment in the recommended spare parts should combine to minimize repair time.

SECTION 9

COST STUDY

A. Costs at the St. Paul Baling Plant.

1. Introduction. Costs are presented separately for the baling plant, transport net, and balefill. These three operations are almost independent of each other, so that their individual costs are independent. Thus, alternative operational methods, such as rail transportation, can be costed and then substituted into the costs for the baling system.

The costs of each part of the system are divided into fixed, operating, and maintenance costs. Fixed costs include investment, property tax and insurance, lost interest, etc. These costs are fixed independently of operating time and production rates. Operating costs include wages, fringes, utility costs, fuel, rental, etc. These costs are nearly proportional to operating time and production. Maintenance costs include labor and parts for both planned maintenance and emergency repairs, but exclude lost production costs (i.e., the dollar value of production not attained). Due to changed accounting information during the period 9/23/73 to 6/27/74, the definition of fixed costs is changed to include fringes.

2. Costs at St. Paul During the Period 10/1/72 to 9/22/73. American Systems of the Harris Economy Group provided the economic data for Tables 9-1 through 9-4. The itemized costs are segmented into fixed, operating, and maintenance costs, but are otherwise as received. During this time period, only minor changes in St. Paul operations occurred, so that costs reflect the true cost of their operations. Two shifts were used Monday through Friday, except holidays.

Operating changes that occurred included implementation of sorting of corrugated. Personnel changes occurred as a new management took over in the spring of 1973, but this did not affect costs.

Two changes that show up in the year's cost data are a seasonal use of cover soil and a change to Company-owned trucks from leased trucks for transporting bales. The use of cover soil was seasonal, with no cover soil applied during some winter months because the frozen soil was difficult to excavate. In August of 1973 a purchased loader arrived for use in moving cover soil and, thus, daily cover was applied thereafter. March, however, shows a large cost for "Grading & Bale Covering" since bales produced during the winter were covered during this time of spring thaw. The use of Company-employed drivers and trucks began in April. This lowered costs for transport operations, but with the observed fluctuations, it is impossible to say exactly how much this cost decreased.

Notice that periodic costs for fuel and oil fluctuate enormously. This follows from bulk purchase of fuel and oil during one month for use in several succeeding months. The year's total cost for fuel and oil is accurate on a long-term basis, while periodic costs for purchase do not necessarily represent expenditures for the respective period. Other

TABLE 9-1
HISTORICAL PRODUCTION DATA
FOR THE PERIOD 10/1/72 TO 9/22/73

Period Production	Oct. 1972	Nov.	Dec.	Jan. 1973	Feb.	Mar.
No. of Bales	7,565	7,358	6,894	7,132	6,717	7,677
kkg Baled	10,138	9,986	9,127	9,273	8,937	10,102
Tons Baled	11,175	11,007	10,061	10,222	9,851	11,135
kkg/Bale	1.34	1.36	1.33	1.30	1.33	1.32
lbs/Bale	2,954	2,992	2,919	2,867	2,933	2,901
Hours of Operation[a]	341	352	331	321	312	355

Period Production	Apr.	May	June	July 1-Aug. 18	Aug. 19-Sept. 22	Total for Year
No. of Bales	4,852	4,996	6,250	9,791	6,615	75,847
kkg Baled	6,363	6,576	8,207	11,764	7,965	98,438
Tons Baled	7,014	7,249	9,046	12,967	8,780	108,507
kkg/Bale	1.31	1.32	1.31	1.20	1.21	1.30
lbs/Bale	2,891	2,902	2,895	2,649	2,655	2,861
Hours of Operation	253	218	283	475	348	3,589

[a] Total time for each work shift including downtime, cleanup, etc.

TABLE 9-2
HISTORICAL COSTS FOR THE BALING PLANT ($)

Period Costs	Oct. 1972	Nov.	Dec.	Jan. 1973	Feb.	Mar.
Fixed	8,485	11,517	7,460	7,460	7,460	7,460
Depreciation[c]	5,444	7,863	5,694	5,694	5,694	5,694
Property						
Insurance	441	1,206	476	476	476	476
Tax	2,600	2,448	1,290	1,290	1,290	1,290
Operating	24,323	21,229	21,259	17,426	23,799	23,982
Wages[a]	13,674	13,872	9,962	9,903	12,021	11,234
Overtime	500	1,087	1,094	491	391	635
Fringes	1,150	717	648	1,311	1,863	1,473
Rental	4,870	2,540	4,983	1,438	5,438	4,698
Electricity	2,476	2,234	2,526	2,637	2,500	2,208
Fuel, Oil	417	180	1,026	--	889	1,562
Telephone	40	(62)[b]	32	3	--	6
Supplies	181	102	112	195	28	218
Other	1,015	559	876	1,448	669	1,948
Maintenance	5,142	1,767	2,874	2,303	4,617	8,638
Total	37,950	34,513	31,593	27,189	35,876	40,080
$/kkg	3.75	3.46	3.46	2.93	4.01	3.97
$/ton	3.40	3.14	3.14	2.66	3.64	3.60
$/bale	5.02	4.69	4.58	3.81	5.34	5.22

[a] Exclude the single administrator and related overhead.

[b] Parentheses mean credit due to money inflowing.

[c] Depreciation and interest rates vary for different equipment in the baling plant (baler and building – 30 years; other equipment varies from 6 to 10 years). Specific interest rates and depreciation schedules were not provided although requested.

TABLE 9-2 (Cont.)
HISTORICAL COSTS FOR THE BALING PLANT

Period / Costs	Apr.	May	June	July 1–Aug. 18	Aug. 19–Sept. 22	Total for Year
Fixed	6,693	8,367	9,377	10,693	10,693	95,665
Depreciation	4,927	6,601	6,601	7,864	7,864	69,940
Property						
Insurance	476	476	476	529	529	6,037
Tax	1,290	1,290	2,300	2,300	2,300	19,688
Operating	18,204	20,873	16,290	30,199	25,234	242,818
Wages	9,952	11,971	9,270	15,825	14,569	132,253
Overtime	1,160	584	1,946	2,173	774	10,835
Fringes	1,281	1,060	1,470	2,548	2,342	15,863
Rental	2,501	3,774	384	4,595	2,387	37,608
Electricity	2,255	1,848	1,900	1,863	2,334	24,781
Fuel, Oil	690	--	380	1,162	2,276	8,582
Telephone	45	17	16	(17)[a]	--	80
Supplies	265	238	736	1,528	342	3,945
Other	55	1,381	188	522	210	8,871
Maintenance	13,704	17,947	3,629	5,433	5,983	72,037
Total	38,601	47,187	29,296	46,325	41,910	410,520
$/kkg	6.06	7.18	3.57	3.94	5.26	4.17
$/ton	5.50	6.51	3.24	3.57	4.77	3.78
$/bale	7.96	9.44	4.69	4.73	6.34	5.41

[a] Parentheses mean money inflowing.

TABLE 9-3
HISTORICAL COSTS FOR THE TRANSPORT NET

Costs \ Period	Oct. 1972	Nov.	Dec.	Jan. 1973	Feb.	Mar.
Fixed	-	-	-	-	-	-
Operating	12,497	12,692	12,692	12,523	12,691	11,863
Wages	-	-	-	-	-	-
Fringes	-	-	-	-	-	-
Truck Rental	-	-	-	-	-	-
Fuel, Oil, & License	-	-	-	-	-	-
Sub-Contract Hauling	12,497	12,692	12,692	12,523	12,691	11,863
Maintenance	-	-	-	-	-	-
Total	12,497	12,692	12,692	12,523	12,691	11,863
$/kkg	1.23	1.27	1.39	1.36	1.42	1.18
$/ton	1.12	1.15	1.26	1.23	1.29	1.07
$/bale	1.65	1.72	1.84	1.76	1.89	1.55

TABLE 9-3 (Cont.)
HISTORICAL COSTS
FOR THE TRANSPORT NET

Period Costs	Apr.	May	June	July 1–Aug. 18	Aug. 19–Sept. 22	Total for Year
Fixed	766	766	766	1,344	1,344	4,986
Depreciation	766	766	766	1,344	1,344	4,986
Operating	6,651	5,932	6,244	11,220	5,298	110,303
Wages	2,491	3,300	3,321	5,600	4,131	18,843
Fringes	206	274	277	467	343	1,567
Trailer Rental	625	1,278	1,278	3,396	-	6,577
Fuel, Oil, & License	843	1,080	1,368	1,757	824	5,872
Sub-Contract Hauling	2,486	-	-	-	-	77,444
Maintenance	999	3,712	2,048	6,600	2,348	15,707
Total	8,416	10,410	9,058	19,164	8,990	130,996
$/kkg	1.32	1.59	1.42	1.63	1.12	1.33
$/ton	1.20	1.44	1.29	1.48	1.02	1.21
$/bale	1.73	2.08	1.45	1.96	1.36	1.73

TABLE 9-4
HISTORICAL COSTS FOR THE BALEFILL

Costs \ Period	Oct. 1972	Nov.	Dec.	Jan. 1973	Feb.	Mar.
Fixed	300	363	312	312	312	312
Depreciation	300	363	298	298	298	298
Property						
Insurance	-	-	14	14	14	14
Tax	-	-	-	-	-	-
Operating	10,407	10,928	8,160	5,700	4,817	14,072
Wages	3,524	4,635	2,094	2,183	2,380	2,876
Overtime	288	562	495	349	256	431
Fringes	292	365	107	272	330	300
Rental	6,573	4,410	4,178	2,487	1,658	988
Fuel, Oil, & License	141	816	1,213	-	254	820
Grading & Bale Covering	-	-	-	-	-	8,482
Supplies	8	116	50	23	-	127
Other	(419)[a]	24	23	386	(61)	48
Maintenance	4,605	639	597	2,898	2,786	846
Total	15,312	11,930	9,069	8,910	7,915	15,230
$/kkg	1.51	1.19	0.99	0.96	0.88	1.51
$/ton	1.37	1.08	0.90	0.87	0.80	1.37
$/bale	2.02	1.62	1.32	1.25	1.18	1.98

[a] Parentheses mean money inflowing.

TABLE 9-4 (Cont.)
HISTORICAL COSTS
FOR THE BALEFILL

Period Costs	Apr.	May	June	July 1–Aug. 18	Aug. 19–Sept. 22	Total for Year
Fixed	312	312	412	555	555	4,057
Depreciation	298	298	298	374	374	3,497
Property						
Insurance	14	14	14	81	81	260
Tax	-	-	100	100	100	300
Operating	7,855	6,720	7,245	10,382	7,140	93,426
Wages	1,972	2,398	1,957	3,090	2,767	29,876
Overtime	333	144	204	349	310	3,721
Fringes	257	227	260	427	355	3,192
Rental	1,638	3,547	1,682	1,684	2,646	31,491
Fuel, Oil, & License	74	258	245	(13)	392	4,200
Grading & Bale Covering	3,583	75	-	4,330	662	17,132
Supplies	-	-	-	56	8	388
Other	(2)[a]	71	2,897	459	-	3,426
Maintenance	172	72	(19)	1,233	235	14,064
Total	8,339	7,104	7,638	12,170	7,930	111,547
$/kkg	1.31	1.08	0.93	1.04	0.99	1.14
$/ton	1.19	0.98	0.84	0.94	0.90	1.03
$/bale	1.72	1.42	1.22	1.24	1.20	1.47

[a] Parentheses mean money inflowing.

fluctuations in fixed costs reflect the number of weeks in the length of the accounting period, nonuniform payments (i.e.,end of amortization, redefined term taxes due, etc.), and monthly estimates with year-end lump-sum adjustments to actual costs. The total for the year is the most accurate account of costs.

3. Costs at St. Paul During the Period 9/23/73 to 6/29/74. American Systems also provided cost data for a second term, but the baler operation closed down before a second full year had passed. Tables 9-5 through 9-8 present the available cost data based for the 1973-74 period. The format is the same as given for the first year (Tables 9-1 through 9-4), minor bookkeeping changes somewhat altered the cost categories. Changes in cost categories were: taxes and fringes lumped; overtime was not listed separately; "telephone-supplier-other" were lumped; and maintenance costs were divided out for the baler plant. Costs during the period from 3/17/74 to 4/20/74 are excluded since experimental evaluations and changes in the baler's chamber lining material were being completed. The costs during these changes were not representative of normal baling plant costs. Cost changes during the last period (5/26/74 to 6/29/74) were observed as a result of closing down procedures, but the changes were insignificant enough to leave the period costs in the comparison. The fluctuation of some costs, such as fuel and depreciation, are the result of accounting practices rather than actual cost changes. They have been included as received.

4. Comparison of Two Record Periods. There is no large cost difference between the periods. Plant operation did become more expensive per bale and per unit weight during 1974, but balefill total cost dropped. The "Energy Crisis" apparently contributed to electricity and fuel cost increases, but a more significant component of the overall unit increase was the drop in quantity of solid waste baled, while operating and maintenance costs remained fixed. Also, increased charges initiated early in 1974 discouraged users who began disposing of unbaled solid wastes at a less expensive local landfill. The basic conclusion drawn from cost data is that solid waste increases requiring operation during more than one shift per day can reduce the costs per unit weight of solid waste baled. Table 9-9 summarizes average costs for both periods.

5. Cost/Profits for Recycling Corrugated Cardboard at St. Paul During the Period 9/23/73 to 4/20/74. Table 9-10 presents monthly costs and profits from recycling corrugated cardboard for the period 8/73 to 4/74, for which data were available. This information indicates that manual sorting and recycling of corrugated cardboard is profitable at the salvage prices prevailing during this period. The price of clean, baled corrugated on the recycling market more than offsets the cost of two laborers' time, amortization of minor items of equipment, and use of baling facilities to bale and ship the cardboard. Details of recycling operations are described in the previous sections.

The baling plant fees charged to solid waste disposers varied according to the type and quantity of solid waste delivered by each vehicle. Data on fees were not available from the baling plant operator and thus were not included. Since the method of estimation used by the gateman was his own visual observation, no attempt was made to derive an estimate from truck volume records, since the trucks were not all filled. If tires and white goods were on the truck, extra special fees were assessed.

TABLE 9-5
HISTORICAL PRODUCTION DATA
FOR THE PERIOD 9/23/73 to 6/29/74

Period / Production	Sept. 23– Oct. 27	Oct. 27–[*] Nov. 30	Dec. 1– Jan. 5	Jan 6– Feb. 9	Feb. 10– Mar. 16
No. of Bales	5,946	4,956	3,784	3,920	4,127
kkg Baled	7,754	6,525	4,942	5,151	5,419
Tons Baled	8,547	7,192	5,448	5,678	5,973
kkg/bale	1.31	1.32	1.31	1.32	1.31
lbs/bale	2,875	2,902	2,879	2,897	2,895

Period / Production	3/17 - 4/20	4/21 - 5/25	5/26 - 6/29	Total To Date
No. of Bales	+	5,956	4,056	32,745
kkg Baled	+	7,845	5,099	42,735
Tons Baled	+	8,648	5,621	47,107
kkg/bale	---	1.32	1.26	1.14
lbs/bale		2,904	2,772	2,516

---

[*] Records use 10/27/73 as both end and start of adjacent periods. Since it was a Saturday, few costs accrued that day.

[+] The plant was down all but three days during this period due to experimental modifications on their chamber liner. Thus, this period is ignored as atypical throughout, including the "Total to Date: column.

TABLE 9-6
HISTORICAL COSTS FOR THE BALING PLANT 9/23/73 to 6/29/74

Period Costs	Sept. 23–Oct. 27	Oct. 27–Nov. 30	Dec. 1–Jan. 5	Jan. 6–Feb. 9	Feb. 10–Mar. 16
Fixed	12,918	23,867	10,241	9,195	9,571
Depreciation	7,864	6,324[*]	6,988	6,988	7,233
Taxes, Fringes	5,054	17,543[*]	3,253	2,207	2,338
Operating	18,485	16,970	12,926	13,930	16,346
Wages	10,315	10,932	8,054	9,175	9,791
Rental	3,866	1,933	1,933	1,933	1,933
Electricity	1,900	1,935	1,998	2,079	3,774
Fuel, Oil	1,680	1,309	230	36	659
Telephone					
Supplies	724	861	711	707	189
Other					
Maintenance	7,118	4,448	5,312	3,577	4,684
Baler	1,718	2,161	2,384	197	508
Conveyor	3,588	148	2,037	0	5
Mobile Equip.	1,190	1,791	566	2,048	2,855
Plant	622	348	325	1,332	1,316
Total	38,521	45,285	28,479	26,702	30,601
\$/kkg	4.98	6.94	5.76	5.18	5.65
\$/ton	4.51	6.30	5.23	4.70	5.12
\$/bale	6.48	9.14	7.53	6.81	7.41

[*] End of accounting year adjustment.

TABLE 9-6 (Cont.)
HISTORICAL COSTS FOR THE BALING PLANT 9/23/73 to 6/29/74

Costs \ Period	Mar. 17- Apr. 20	Apr. 21- May 25	May 26- June 29	Total To Date
Fixed	*	9,638	9,510	84,940
Depreciation		7,233	7,233	49,863
Taxes, Fringes		2,405	2,277	35,077
Operating	*	16,131	13,878	108,666
Wages		9,044	9,169	66,480
Rental		2,472	0	14,070
Electricity		1,926	2,588	16,200
Fuel, Oil		1,705	1,248	6,867
Telephone				
Supplies		984	873	5,049
Other				
Maintenance	*	4,830	4,111	34,080
Baler		509	433	7,910
Conveyor		19	16	5,813
Mobile Equip.		2,946	2,508	13,904
Plant		1,356	1,154	6,453
Total		30,599	27,499	227,686
$/kkg	---	3.90	5.39	5.33
$/ton	---	3.54	4.89	4.83
$/bale	---	5.14	6.78	6.95

*The plant was down all but three days during this period due to experimental modifications on the chamber liner. Thus, this period is ignored as atypical. The "Total to Date" column also ignores this period.

TABLE 9-7
HISTORICAL COSTS FOR THE TRANSPORT NET 9/23/73 to 6/29/74

Period Costs	Sept. 23- Oct. 27	Oct. 27- Nov. 30	Dec. 1- Jan. 5	Jan. 6- Feb. 9	Feb. 10- Mar. 16
Fixed	1,683	1,750	1,368	1,165	3,191
Depreciation	1,344	1,344	919	919	2,800
Taxes, Fringes	339	406	449	246	391
Operating	9,235	7,193	5,196	6,465	5,205
Wages	4,089	4,897	3,569	2,885	2,786
Fuel, Oil	817	1,149	969	2,329	1,761
Rental	4,329	1,147	658	1,251	658
Maintenance	1,633	2,280	921	2,245	1,953
Total	12,551	11,223	7,485	9,875	10,349
$/kkg	1.62	1.72	1.51	1.92	1.91
$/ton	1.47	1.56	1.37	1.74	1.73
$/bale	2.11	2.26	1.98	2.52	2.51

TABLE 9-7 (Cont.)
HISTORICAL COSTS FOR THE TRANSPORT NET 9/23/73 to 6/29/74

Period / Costs	Mar. 17–Apr. 20	Apr. 21–May 25	May 26–June 29	Total To Date
Fixed	*	3,339	3,180	15,676
Depreciating		2,800	2,800	12,926
Taxes, Fringes		539	380	2,750
Operating	*	6,110	3,218	42,622
Wages		4,222	2,391	24,839
Fuel, Oil & License		1,230	169	8,424
Rental		658	658	9,359
Maintenance	*	3,058	103	12,193
Total	*	12,507	6,501	70,491
$/kkg	---	1.59	1.27	1.65
$/ton	---	1.45	1.16	1.50
$/bale	---	2.10	1.60	2.15

* The plant was down all but three days during this period. Thus this period is ignored.

TABLE 9-8
HISTORICAL COSTS FOR THE BALEFILL 9/23/73 to 6/29/74

Period Costs	Sept. 23- Oct. 27	Oct. 27- Nov. 30	Dec. 1- Jan. 5	Jan. 6- Feb. 9	Feb. 10- Mar. 16
Fixed	1,617	2,079	860	709	642
Depreciation	1,124	(72)*	498	498	498
Taxes, Fringes	493	2,151*	362	211	144
Operating	4,978	4,793	6,693	2,846	3,034
Wages	2,925	3,054	2,718	1,459	1,559
Rental	1,661	1,194	3,476	1,056	1,036
Fuel, Oil	392	499	375	325	439
Grading & Bale Covering	---				
Supplies	---				
Other	---	46	124	6	---
Maintenance	1,130	1,984	407	684	754
Total	7,725	8,856	7,960	4,239	4,430
$/kkg	1.00	1.36	1.61	0.82	0.82
$/ton	0.90	1.23	1.46	0.75	0.74
$/bale	1.30	1.79	2.10	1.08	1.07

*End of accounting year adjustment.

TABLE 9-8 (Cont.)
HISTORICAL COSTS FOR THE BALEFILL 9/23/73 to 6/29/74

Period Costs	Mar. 17–Apr. 20	Apr. 21–May 25	May 26–June 29	Total To Date
Fixed	*	687	627	7,221
Depreciation		498	498	3,542
Taxes, Fringes		189	129	3,679
Operating	*	3,651	5,062	31,057
Wages		2,552	1,541	15,808
Rental		1,035	1,009	10,467
Fuel, Oil		64	213	2,307
Grading & Bale Covering				
Supplies			2,299	2,475
Other				
Maintenance	*	167	559	5,685
Total	*	4,505	6,248	43,963
$/kkg	---	0.57	1.23	1.03
$/ton	---	0.52	1.11	0.93
$/bale	---	0.76	1.54	1.34

* The plant was down all but three days during this period. Thus this period is ignored.

TABLE 9-9
SUMMARY COSTS
($)

Location	Type Cost	Cost/Bale		Cost/kkg		Cost/Ton	
		First *	Second *	First	Second	First	Second
Baling Plant	Fixed +	1.26	2.59	0.07	1.99	0.88	1.80
	Operating +	3.20	3.32	2.47	2.24	2.24	2.31
	Maintenance	0.95	1.04	0.73	0.80	0.66	0.72
	Total	5.41	6.95	4.17	5.33	3.78	4.83
Transport Net	Fixed +	0.07	0.48	0. 5	0.37	0.05	0.33
	Operating +	1.45	1.30	1.12	1.00	1.02	0.91
	Maintenance	0.21	0.37	0.16	0.28	0.14	0.26
	Total	1.73	2.15	1.33	1.65	1.21	1.50
Balefill	Fixed +	0.05	0.22	0.04	0.17	0.04	0.15
	Operating +	1.23	0.95	0.95	0.73	0.86	0.66
	Maintenance	0.19	0.17	0.14	0.13	0.13	0.12
	Total	1.47	1.34	1.13	1.03	1.03	0.93
System	Fixed +	1.38	3.29	1.06	2.53	0.97	2.28
	Operating +	5.89	5.57	4.54	4.27	4.12	3.88
	Maintenance	1.34	1.58	1.03	1.21	0.93	1.10
	Total	8.61	10.44	6.63	8.01	6.02	7.26

* "First" refers to the first year from 10/1/72 to 9/22/73 while "second" refers to the second, incomplete, year from 9/23/73 to 6/29/74.

+ There were minor modifications in the definition of fixed and operating costs between years.

TABLE 9-10
HISTORICAL COSTS FOR RECYCLING CORRUGATED CARDBOARD ($)

Period / Item	9/23/73 - 10/27	10/28 - 12/1	12/2/73 - 1/5/74	1/6/74 - 2/9	2/10 - 3/16	3/17 - 4/20	9/23/73 -4/20/74
Income	5,834	7,360	7,170	5,485	6,780	5,290	37,919
Cost[a]	1,663	1,877	2,341	2,207	1,957	2,002	12,047
Net Profit	4,171	5,483	4,829	3,278	4,823	3,288	25,872
Solid Waste							
kkg	8,034	7,754	6,525	4,942	5,151	5,419	37,825
ton	8,856	8,547	7,192	5,448	5,678	5,973	41,694
Profit/kkg	0.52	0.71	0.74	0.66	0.94	0.61	0.68
Profit/ton	0.47	0.64	0.67	0.60	0.85	0.55	0.62

[a] Includes labor for segregating the cardboard, plus baling costs at $6.95 per bale.

B. Processing and Cost Comparison of Alternative Solid Waste Processing Systems.

1. General Processing Methods. Several alternative solid waste processing systems are currently in use; these include baling, milling, incineration, and composting. The former two are physical-mechanical processes; the latter two may be considered thermal and biological-type chemical processes. Modern incineration which has to meet stringent air pollution standards is expensive and requires costly pollution controls. Composting is generally not done because of cost and a lack of markets for the compost product, particularly near urban areas. Long-distance hauling of bulky compost to agricultural areas would be costly, even if markets existed. Baling and milling have advantages in that they are relatively non-polluting to the air and water and are suited to urban areas due to plant facilities having minimum land requirements and possibly reduced transportation costs due to lesser waste volumes. Bales and millings are not expected to affect land any more severely than normal unprocessed solid waste when disposed to land. These two processes are evaluated with regard to their relative merits, since they have the similar purpose of increasing the density of landfilled waste. The analysis summarized in this section compares the following general physical-mechanical processing system configurations on the basis of relative cost and describes potential environmental effects of landfilling alternative types of processed wastes:

a. High-density baling. American Hoist and Derrick Company, Harris high-density baler with conveyor/front-end loader materials feed system as operated in St. Paul, Minnesota.

b. High-density baling. Harris high-density baler with an overhead crane materials-feed concept.

c. Milling. The Tollemache and Gondard mill operated as a demonstration plant in Madison, Wisconsin.

d. Combined milling and low-pressure baling. A mill and American Baling Company low-pressure baler operated as a demonstration plant by the City of San Diego, Calif.

These four systems were selected due to their being recently or presently in operation on a full-scale basis as either federal Environmental Protection Agency demonstrations or pilot plants with relatively good data. Alternative b. has not been operated as a complete system, but the Harris high-density baler is a similar baler to the one used in St. Paul. Capital, operating, and maintenance cost and technical data presented here were available for each system at the time the study was completed, and thus provide a useful comparative assessment of the four system configurations.

Baling and milling processes are generally suitable for application to residential and commercial solid waste. The Harris high density baler is also suitable for baling paper and scrap metal. Economic advantages associated with baling are reduced volume and reduced soil cover costs and associated landfill placement and maintenance costs over unprocessed landfilled solid wastes. Bales are easier and less costly to place in the fill than unprocessed and milled wastes, which both require spreading and compaction to achieve high densities. Milled wastes, which some authorities say require less soil cover when landfilled, also have some of these aforementioned economic advantages over unprocessed landfilled wastes. However (obviously), baling and milling cost more than dumping or plain landfilling. Both baled and milled solid waste achieve about a 50 percent increase in landfill density over unprocessed solid waste (see Table 9-22), thus reducing landfill and storage requirements by about one-third. The higher density also means less settlement (both absolute and differential), and, thus, a higher potential use for the filled land. If the baler or mill is inoperative for an extended time, the solid waste could be temporarily disposed into the landfill unprocessed.

Environmental benefits associated with bale landfills include fewer vectors, less litter, and minimum odors. This occurs as a result of the reduced surface area of the tightly packed waste and lack of void passages through which odors can diffuse and birds, flies, or other vectors can traverse to food. The same environmental benefits were reported for milling; however, the cause was due to dispersion of finely milled food stuff into the milled waste so that it was difficult for vectors to forage.

Mechanical processing of solid waste has stimulated salvaging and reclamation. For example, milled solid waste has been used in a federal EPA demonstration project as an auxiliary fuel for an electrical power plant. Corrugated cardboard and ferrous metal segregation and salvage for baling was done by hand at the St. Paul baling plant. Although most labor-intensive salvage operations were not economically feasible, more sophisticated ferrous metal segregation, such as using magnetic belts, has been profitable for shredded waste at several locations.[1] Milling plants can easily accommodate magnetic segregation on the existing conveyors. Salvage and recycling operations are omitted from the comparative system analysis, due to local variations in salvageable materials in the solid waste and the fact that reclamation is presently not widely practiced. In the future, regional landfills will likely become more important to reduce costs and provide for economical recycling to meet increased consumption requirements for dwindling resources. In order to serve more distant regional landfills, transfer stations will be required, thus providing suitable locations for baling and milling plants.

Perhaps the greatest disadvantage of either baling or milling is the relatively large initial capital outlay required for the equipment. This and the high processing rates necessary to cover the capital costs make baling and milling feasible primarily for regional or large urban areas.

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[1] John J. Reinhardt and Robert K. Ham, Final Report on a Milling Project at Madison, Wisconsin, Vol. 1 (Milwaukee: Heil, 1973).

2. Systems Comparison.

a. General Assumptions. Comparison of different operating systems using available data is complicated by local variations in costs (construction, land, supplies, utilities, and labor), climate, solid waste characteristics, operating plant capacity, and accounting procedures. If the plants operated during different time periods, the effects of inflation must be normalized. Granting that these differences exist between the systems (as operated), a meaningful analysis is possible by equalizing application of each system in terms of the different cost and operating factors.

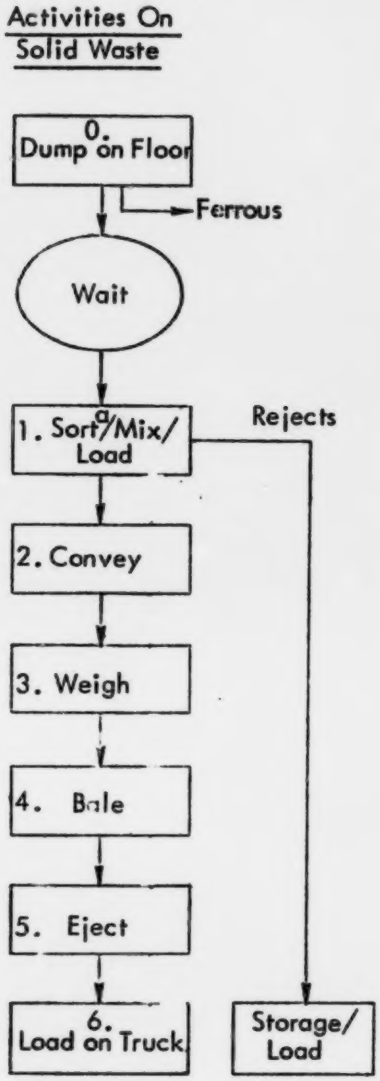
The basic year for costing was selected as 1973. This was done because 1973 construction cost data was available for a high-density Harris baler under construction in Cobb County, Georgia. The Cobb County costs for construction contingencies and equipment were used for costing of identical baling plant equipment for comparing the four baling and milling process configurations. Capital costs for milling were based on the Madison plant cost analysis, and for combined milling and baling data the San Diego plant was used. Since each of the four processes systems assume nearly equivalent solid waste processing rates, similar equipment sizes and costs were used. The Engineering News Record Construction Cost Index was employed to adjust the Madison and San Diego reported costs. Standard labor rates were selected as representative of existing landfill, truck driver, and plant operating personnel in solid waste management at St. Paul and Madison; available data on Oceanside, California was used as typical of San Diego. Labor rates in these three cities varied widely and were assumed to be typical of the wide variations nationally. Interest rates on capital were based on current rates on municipal bonds. Supplies and other miscellaneous costs were based on data from the St. Paul baling plant. Operating and maintenance costs were derived from operations at the three respective plants and adjusted to the standard labor rates.

A standard travel distance of 11 miles one-way between the transfer-processing plant and landfill, identical to conditions in St. Paul, was assumed for all four systems to determine transport costs.

Segregation and recycling were excluded from the cost analysis to simplify the direct comparison of the four alternative processing systems. Segregation of ferrous metals and corrugated paper for salvage might be feasible for inclusion in all four systems.

b. High Density Baling--System I. The baling plant operations schematic and equipment are presented in Figure 9-1. The System I configuration is the same as operated in St. Paul. (Equipment specifications are given in Appendix C.) For purposes of analysis, the current baler model with a 90-second baling cycle was used. The equipment used is otherwise identical to the St. Paul equipment in size. The System I baling plant operational conditions are as follows:

- Operating cycle - 1.9 minutes per bale which includes lost time.
- Production rate - 31.5 bales per hour, or 41.6 kkg (45 s tons) per hour.


Activities On Solid Waste
0. Dump on Floor
Ferrous
Wait
1. Sort[a]/Mix/ Load
Rejects
2. Convey
3. Weigh
4. Bale
5. Eject
6. Load on Truck
Storage/ Load

Equipment Used

0. Collection Trucks
1. Wheel Loader
2. Two Slat Conveyors
3. Automatic Scale
4. Baler
5. Ejector
6. Transport Trucks

[a] Sorting for recyclables is possible. Recyclables are baled separately as in the cases of cans and corrugated.

FIGURE 9-1
HIGH DENSITY BALER SYSTEM 1
OPERATION SCHEMATIC

- Bale weight - 910 kg (2,000 lb) to 1,360 kg (3,000 lb), average 1,320 kg (2,900 lb).
- Bale size - 1.1 m high by 1.1 m wide by 1.4 m long
- Bale density range - 960 kg per cu m to 640 kg per cu m.
- Production schedule - 8 hours per shift, 2 shifts per day, 14 production hours per day, 49 weeks per year.

Additional peripheral equipment utilized in the plant, but not on the processing activity line, were an articulated forklift and small "bobcat" wheel loader. These performed clean-up, equipment and supplied handling,and general transport tasks. It was assumed that the forklift was not used to lift the bale truck loading platform above the transport truck bed.

The complete system included four transport trucks (tractors and trailers) to carry bales to a landfill. Landfill activities and equipment consist of the following:

- De-rigging transport trucks to make bales accessible.
- Unloading and placing bales three-high in the fill with an articulated, wheeled forklift.
- Excavating soil and covering bales daily with 15 cm (6 inches) of soil using an articulated, wheel loader.

Landfill operating hours and shifts corresponded to the baling plant operation.

The capital (construction) costs for System I are itemized in Table 9-11. A 20 percent contingency is included in accordance with conservative engineering cost practices. Operating and maintenance costs for System I are defined in Table 9-12. Labor classifications and manpower levels, and hourly rates are included in Table 9-12. In order to estimate maintenance costs, a preventive maintenance program was assumed during two production shifts,with heavier maintenance being performed after the second shift. Electrical power consumption in kilowatts was estimated using the rated maximum power requirements of the electrical driven equipment (motors, etc.) and assuming a constant demand equal to 50 percent of maximum demand. This assumption was necessary due to a lack of kilowatt-hour power consumption data in St. Paul. Costs for land were not included due to the assumption that the land value before and after baling or landfilling would be the same (no net cost). Due to the relative completeness of data from the St. Paul plant, System I costs are considered more accurate statistically, and are probably more conservative than the other systems due to the latter's missing items.

c. High Density Baling-System II. The baling plant operations schematic and equipment are identified in Figure 9-2. The System II configuration substitutes a travelling overhead crane for the front-end wheel loader and conveyor in System I. All other equipment and baling plant operational conditions, and transport and landfill operations are as stated for System I. The loader operator was eliminated. The control tower

TABLE 9-11
HIGH-DENSITY BALING SYSTEM I - CONSTRUCTION COSTS[a,b]

Item		Cost ($)
1. Baler		676,200
2. Conveyors (2)		122,500
3. Automatic Scales		40,000
4. Hydraulic Bale Loader		25,000
5. Supporting Equipment		
a) Wheel Loaders (2)		90,000
b) Forklift		10,000
c) Miscellaneous		25,000
6. Building (120 ft x 240 ft) @ $\$16/\text{ft}^2$		460,800
7. Equipment Footing and Pits		120,000
8. Pavement		50,000
	Subtotal	1,619,500
9. Transport Trucks (4)		100,000
10. Articulated Forklift		10,000
11. Wheel Loader		45,000
12. Balefill Building and Fuel Tanks		21,000
13. Site Improvements		0
	Subtotal	176,000
	Base Total	1,795,500
20 Percent Architecture, Engineering, and Contingency		359,100
	Total	2,154,600

[a] Based on 1.9 minute per bale cycle time and 1320 kg /bale (2900 lbs/bale) weight; also assumes 41.5 kkg/hr (45.7 s ton/hour) operating capacity

[b] Based on cost at Cobb County, Georgia, in 1973. Source for most cost data was a personal communication from the Harris Economy Group of American Hoist and Derrick Company (November 30, 1973), the cost data for Items 5c and 13 were estimated.

TABLE 9-12

HIGH-DENSITY BALING SYSTEM I - OPERATING AND MAINTENANCE COSTS[a]

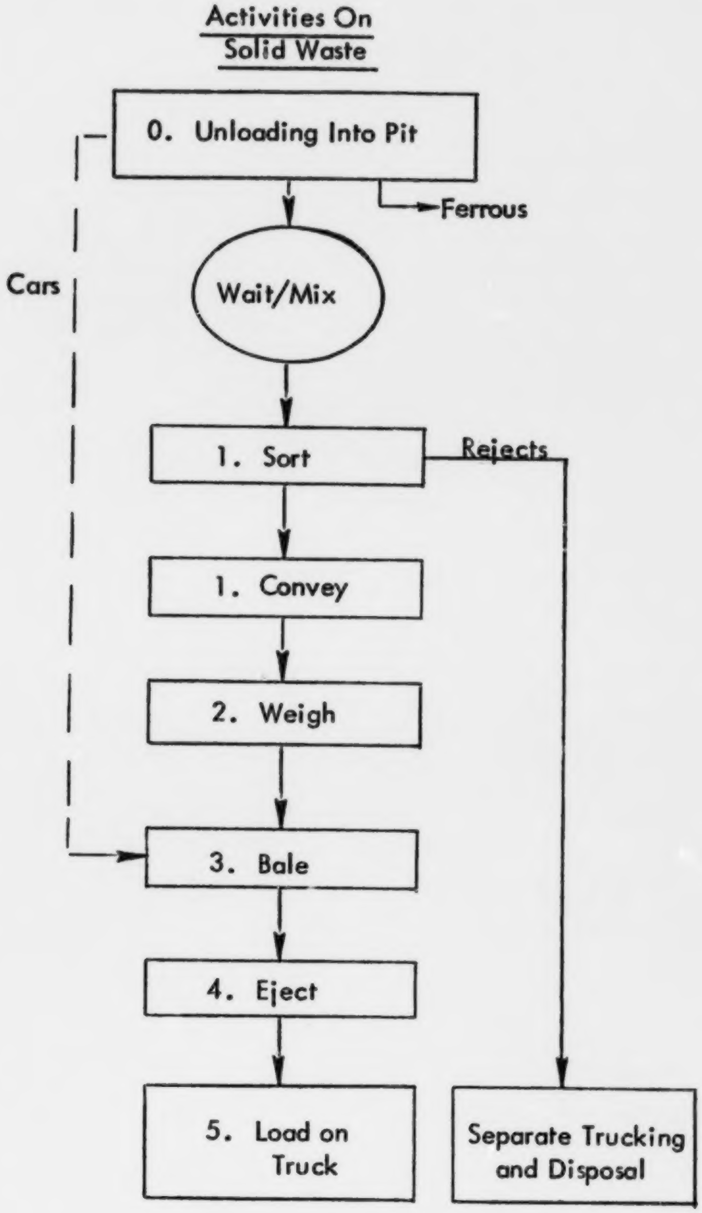
Item		Work Week Costs ($)	
		5 Day/Wk	6 Day/Wk
1. Labor	Rate ($/hr)		
a) Supervisor	6.50	12,740	12,740
b) Control Tower Operators (1-1-0)[b]	6.50	25,480	30,576
c) Loader Operators (1-1-0)	6.50	25,480	30,576
d) Mechanics (1-1-1)	5.50	32,340	38,808
e) Maintenance Men (1-0-1)	4.50	17,640	21,168
f) Truck Drivers (2-2-0)	5.50	43,120	51,744
g) Fill Operators (1-1-0)	6.50	25,480	30,576
		182,280	216,188
30 percent Cost/Benefits		54,684	64,856
Subtotal		236,964	281,044
2. Electricity			
a) Hydraulic Pumps (4) @ 112 kw; (2) @ 19 kw; (1) @ 2 kw		487	
b) Conveyors (2) @ 18 kw		36	
c) Lights		40	
		563	563 (kw)
Use @ 50 percent capacity x		1,715	2,058 (hrs)
		965,545	1,158,654 (kwhr)
Cost @ $.015/kwhr		x .015	x .015
$		14,483	17,380
3. Fuel/Oil[c]		16,000	19,200
4. Maintenance Parts		101,000	121,000
Subtotal		131,483	157,580
		(368,447)	(438,624)
Annual Total		368,000	439,000

---

[a] Assumes 49 weeks per year, 14 production hrs per day, and 8 hrs per shift.

[b] Numbers in parentheses refer to number of employees required for first, second and maintenance shifts, respectively.

[c] Assumes 35.2km (22-mile) round-trip distance to balefill.


Activities On Solid Waste
0. Unloading Into Pit
Ferrous
Wait/Mix
Cars
1. Sort
Rejects
1. Convey
2. Weigh
3. Bale
4. Eject
5. Load on Truck
Separate Trucking and Disposal

Equipment Used

0. Collection Trucks (Weight Station)
1. Overhead Crane
2. Scale
3. Baler
4. Ejector
5. Transport Trucks

FIGURE 9-2
HIGH DENSITY BALER SYSTEM II
OPERATION SCHEMATIC

operator controlled the waste loading and ran the overhead crane.

The construction costs, and the operating and maintenance costs for System II are given in Tables 9-13 and 9-14, respectively. All cost assumptions are as previously stated for System I. The System II configuration reduced construction costs by $200,000, and operating and maintenance costs by $21,000 due to the use of the crane and reduced labor. It was assumed that maintenance time and cost savings would occur by use of the travelling crane.

d. Tollemache Mill--System III. The milling plant operations schematic is given in Figure 9-3. The System III configuration used the Tollemache hammermill adapted to shredding solid waste by rearrangement of the "hammers." Each mill can process 12.7 kkg (14 s tons) per hour. For comparison purposes, three parallel line Tollemache mills were used for System III to provide a total plant capacity approximately equal to the baling systems. The equipment was otherwise identical to the Madison plant.[1] The applicable System III milling plant operational conditions were as follows:

- Production rate - 38.1 kkg (42 s tons)
- Production schedule - 8 hours per shift, 2 shifts per day, 14 production hours per day, 49 weeks per year.

Additional peripheral equipment at the milling plant consisted of a forklift to assist in lifting heavy objects and segregating items not suitable for milling. Two belt conveyors were required for each Tollemache mill, one to feed unmilled waste and one to remove milled waste. A stationary compactor compressed and pushed the milled waste into an enclosed trailer van. The trailer van had a hydraulic ram to unload the milled waste at the landfill.

The transport system consisted of four truck tractors and trailer vans. Landfill activities and equipment consisted of the following:

- Unloading transport trucks using the trailer hydraulic pusher.
- Spreading and compacting the milled waste using two steel-wheel loaders. The milled waste can be placed in the landfill without, or with less, covering of soil, thus reducing the need for excavating and placing cover soil. Landfill operating hours and shifts correspond to the milling plant operation.

Construction costs for the milling System III are itemized in Table 9-15 and operating and maintenance costs in Table 9-16. Labor classifications, requirements and hourly rates are included on Table 9-16. Construction costs for the mill, conveyors and compactor were based on projected data in the Madison final report. Three processing lines (mills) were costed for installation in one building. Mobile equipment, building

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[1] Ibid.

TABLE 9-13
HIGH DENSITY BALING SYSTEM II - CONSTRUCTION COSTS

Item		Cost ($)[a, b]
1. Baler		676,200
2. Overhead Crane		55,000
3. Automatic Scales		40,000
4. Hydraulic Bale Loader		25,000
5. Supporting Equipment		
a) Medium Wheel Loader		25,000
b) Forklift		10,000
c) Miscellaneous		25,000
6. Building (120 ft x 200 ft) @ $16/ft^2		384,000
7. Equipment Footings, Pits, & Crane Support		160,000
8. Pavement		50,000
	Subtotal	1,450,200
9. Transport Trucks (4)		100,000
10. Articulated Forklift		10,000
11. Wheel Loader		45,000
12. Balefill Building and Fuel Tanks		21,000
13. Site Improvements		,0
	Subtotal	176,000
	Base Total	1,626,200
	20 Percent Engineering and Contingency	325,240
	Total	(1,951,440) 1,950,000

[a] Based on 1.9 minutes per bale cycle time and 1,320 kg/bale (2,900 lbs/bale) weight; also assumes 41.5 kkg/hr (45.7 ton/hour) operating capacity.

[b] Based on cost at Cobb County, Georgia, in 1973. Source for most cost data was a personal communication from the Harris Economy Group of American Hoist and Derrick Company; the remaining cost data were estimated for the Cobb County plant.

TABLE 9-14
HIGH-DENSITY BALING SYSTEM II-OPERATING AND MAINTENANCE COSTS[a]

Item		Work Week Basis, Cost ($)	
		5 Day/Wk	6 Day/Wk
1. Labor (8-hour shifts)	Rate ($/hr)		
a) Supervisor	6.50	12,740	12,740
b) Control Tower Operators (1-1-0)[b]	6.50	25,480	30,576
c) Mechanics (1-1-1)	5.50	32,340	38,808
d) Maintenance Man (1-1-1)	4.50	26,460	31,752
e) Truck Drivers (2-2-0)	5.50	43,120	51,744
f) Fill Operators (1-1-0)	6.50	25,480	30,576
		165,620	196,196
30 percent Cost/Benefits		49,686	58,858
Subtotal		215,306	255,054
2. Electricity			
a) Hydraulic Pumps (4) @ 112 kw; (2) @ 19 kw; (1) @ 2 kw		487	
b) Overhead Crane ~ 36 kw		36	
c) Lights[a]		40	
		563	563 (kw)
Use @ 50 percent capacity		x 1,715	x 2,058 (hrs)
		965,545	1,158,654(kwhr)
Cost @ $0.15/kwhr		x .015	x .015
		14,483	17,380
3. Fuel/Oil[c]		16,000	19,200
4. Maintenance Parts		101,000	121,000
Subtotal		131,483	157,580
		(346,789)	(412,634)
Annual Total		347,000	413,000

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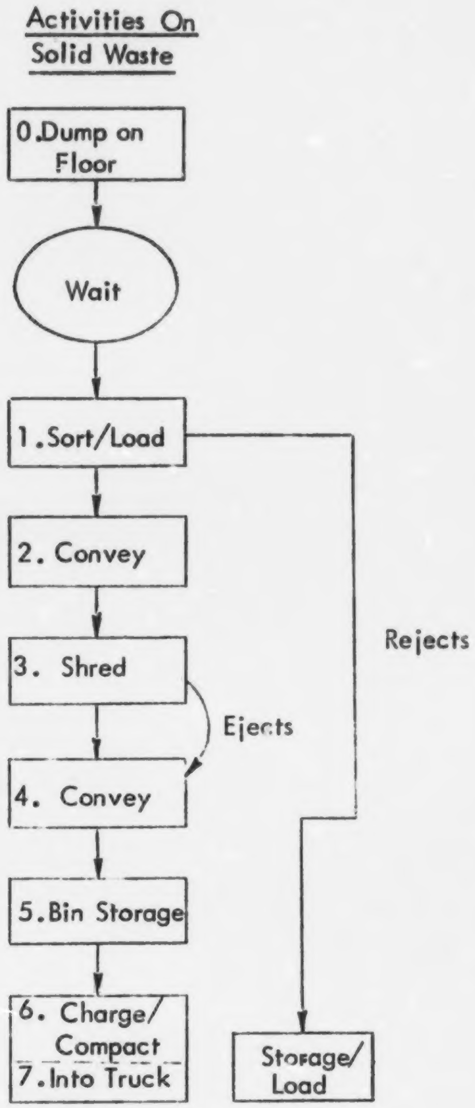
[a] Assumes 49 weeks/year, 14 production hrs/day, and 8 hrs/shift.

[b] Numbers in parentheses refer to number of employees required for first, second, and maintenance shifts, respectively.

[c] Assumes 35.2 km (22-mile) round-trip distance to balefill.


Activities On Solid Waste
0.Dump on Floor
Wait
1.Sort/Load
2. Convey
3. Shred
Ejects
4. Convey
5.Bin Storage
6. Charge/ Compact
7.Into Truck
Rejects
Storage/ Load

Equipment Used

0. Collection Trucks
1. Wheel Loader
2. Belt Conveyor
3. Shredder
4. Belt Conveyor
5. Compactor Storage Bin
6. Stationary Compactor
7. Transport Truck

FIGURE 9-3
MILL SYSTEM
OPERATION SCHEMATIC

TABLE 9-15
MILL SYSTEM-CONSTRUCTION COSTS[a, b]

	Item	Cost ($)
1.	Tollemache Mills (3) with Conveyors	445,000
2.	Compactors (2)	47,000
3.	Wheel Loaders (2)[c]	90,000
4.	Forklift[c]	10,000
5.	Miscellaneous[c]	25,000
6.	Building (120 ft x 240 ft) @ $16/ft^2	460,000
7.	Equipment Supports and Pits	35,000
8.	Paving[c]	50,000
	Subtotal	1,162,000
9.	Transport Trucks with Compactors (4)	136,000
10.	Steel-wheel Loaders (2)[c]	90,000
11.	Millfill Building and Fuel Tanks[c]	21,000
12.	Site Improvements	0
	Subtotal	247,000
	Base Total	1,409,000
	20 percent Architecture, Engineering, and Contingency	281,800
		(1,690,800)
	Total	1,690,000

[a] Based on 12.7 kkg/hr (14 s ton/hr) at Madison, Wisconsin, times three mills. Assumes 38.1 kkg/hr (42 s ton/hr) operating capacity.

[b] Source: Reinhardt, J. J., and Ham, R. K. Final Report on a Demonstration Project at Madison, Wisconsin to Investigate Milling of Solid Wastes. Volume I: 1966-1972. E.P.A. Office of Solid Waste Management Programs. March 1973. pp.104-122.

[c] Based on cost at Cobb County, Georgia, in 1973.

TABLE 9-16
MILL SYSTEM-OPERATING AND MAINTENANCE COSTS[a, b]

Item		Work Week Basis, Cost ($)	
		5 Day/Wk	6 Day/Wk
1. Labor (8-hour shifts)	Rate ($/hr)		
a) Supervisor	6.50	12,740	12,740
b) Mill Operators (2-2-0)[c]	5.50	43,120	51,744
c) Loader Operators (1-1-0)	6.50	25,480	30,576
d) Mechanics (1-1-1)	5.50	32,340	38,808
e) Maintenance Men (1-1-1)	4.50	26,460	31,752
f) Truck Drivers (2-2-0)	5.50	43,120	51,744
g) Fill Operators (1-1-0)	6.50	25,480	30,576
		208,740	247,940
30 percent Cost/Benefits		62,622	74,382
Subtotal		271,362	322,322
2. Electricity[a]			
a) Mills (3) @ 149 kw		447	
b) Conveyors (6) @ 5.5 kw		33	
c) Compactors (2) @ 20 kw		40	
d) Lights		40	
		560	560 (kw)
Use @ 50 percent capacity		x 1,715	x 2,058 (hrs)
		960,000	1,152,480 (kwhr)
Cost @ $.015/kwhr		x .015	x .015
		14,406	17,287
3. Fuel/Oil		16,000	19,200
4. Maintenance Parts			
a) Mills		53,040	63,640
b) Other		45,000	54,000
Subtotal		128,446	154,127
		(399,808)	(476,449)
Annual Total		400,000	476,000

[a] Assumes 49 weeks/year, 14 production hrs/day, and 8 hrs/shift.

[b] Most data modified from St. Paul baling plant annual operating costs for two five-day shifts. Costs for Items 2 and 4 (a) obtained from Reinhardt and Ham, op. cit., pp 104-122.

[c] Numbers in parentheses refer to number of employees required for first, second and maintenance shifts, respectively.

and site construction improvement costs were based on the current 1973 Cobb County, Georgia and updated 1973 construction costs for the other locations. Operating and maintenance for mobile equipment was costed in an identical manner to the baling Systems I and II, except for the truck trailer vans. Equipment maintenance costs and electrical power consumption for stationary equipment were derived from the Madison report. Costs for land were excluded for all the systems.

e. Combined Milling and Low-Pressure Baling--System IV. A schematic depicting the milling-baling plant operations is given in Figure 9-4. The plant configuration was identical to the demonstration plant operated by the City of San Diego.[1] A Williams No. 475 shredder and American Baler Company Model 12475 baler were used as the basis for this process configuration. A materials feed arrangement was used that included a vertical bucket-type elevator conveyor; it caused operating problems from waste materials jamming the bucket conveyor mechanism. One milling-baling plant had a capacity of 19.5 kkg (21.5 s tons) per hour based on San Diego operating data. The milling-baling plant operational conditions were as follows:

- Production rate - 39 kkg (43 s tons) per hour (for two plant process lines).
- Production schedule - 8 hours per shift, 2 shifts per day, 14 production hours per day, 49 weeks per year.

Other plant equipment consisted of a forklift which was used to move heavy items and equipment.

The transport system included four tractor-trailer units identical to the high-density baling Systems I and II bale transport trucks.

Landfill activities and equipment were also identical to Systems I and II, e.g., trucks were de-rigged, bales were unloaded and placed in the fill by a forklift, and 15.2 cm (6 inches) of daily cover soil was applied by a loader.

Construction, and operating and maintenance costs (including labor breakdowns) are given in Tables 9-17 and 9-18, respectively. The San Diego plant operated on a pilot-scale basis, thus costs were modified for full-scale operation. Two processing lines are costed for installation in one building. The operating and maintenance cost summary is considered to be the least accurate due to the experimental type of plant operated in San Diego.

4. System Cost Comparison. The basic plant production equipment and production rates for the four systems are summarized in Table 9-19. The plant production rates were basically equal.

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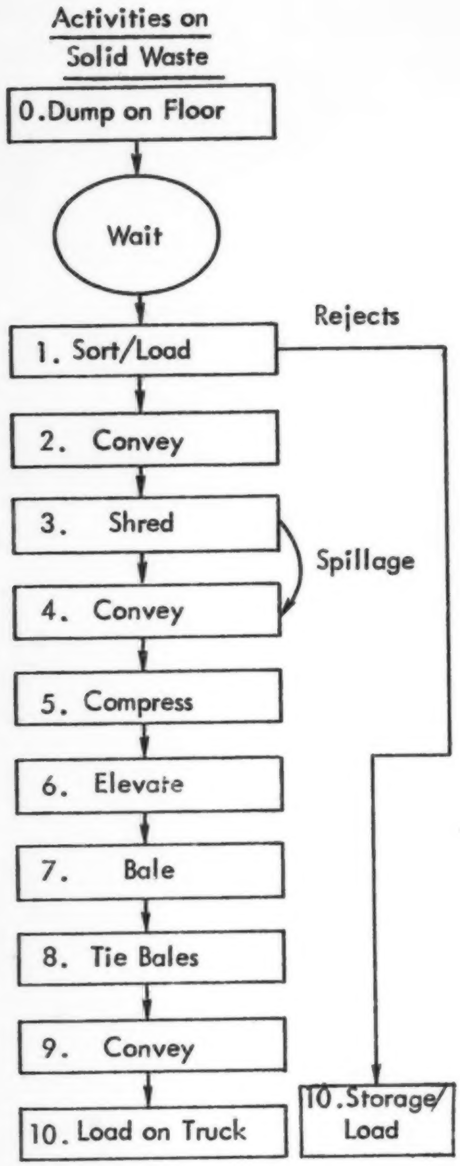
[1] The Feasibility of Baling Municipal Refuse. Public Works Department, City of San Diego, California, October 1968; and Baling Municipal Solid Waste: Technical Evaluation. Public Works Department, City of San Diego, June 1973.


Activities on Solid Waste
0. Dump on Floor
Wait
1. Sort/Load
Rejects
2. Convey
3. Shred
Spillage
4. Convey
5. Compress
6. Elevate
7. Bale
8. Tie Bales
9. Convey
10. Load on Truck
10. Storage/ Load

Equipment Used

0. Collection Truck
1. Wheel Loader
2. Pan Conveyor
3. Shredder
4. Spillage Belt Conveyor
5. Doffer Roller
6. Elevator
7. Baler
8. Baler
9. Roller Conveyors
10. Transport Truck

FIGURE 9-4
MILLING, BALING SYSTEM
OPERATION SCHEMATIC

TABLE 9-17
COMBINED MILLING, BALING SYSTEM - CONSTRUCTION COSTS[a,b]

Item	Cost ($)
1. American Baler	52,500
2. Shredder	86,300
3. Pan Conveyor	40,600
4. Slider Bed Conveyor	8,000
5. Bucket Elevator	21,600
6. Live Rollon Conveyor	3,000
7. Scale-Section Conveyor	6,200
8. Gravity Conveyor	1,800
9. Air Compressor	600
	220,600
Times 2 Plants	441,200
10. Wheel Loaders[c] (2)	90,000
11. Forklift[c]	10,000
12. Miscellaneous[c]	25,000
13. Building (120 ft x 290 ft) @ $\$16/\text{ft}^2$	556,800
14. Equipment Footings	50,000
15. Paving	50,000
Subtotal	1,223,000
16. Transport Trucks (4)	100,000
17. Articulated Forklift[c]	10,000
18. Wheel Loader[c]	45,000
19. Balefill Building and Fuel Tanks[c]	21,000
20. Site Improvements	0
Subtotal	176,000
Base Total	1,339,000
20 Percent Architecture, Engineering, and Contingency	267,800
	(1,606,800)
Total	1,607,000

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[a] Based on 19.5 kkg/hr (21.5 s ton/hr) in San Diego. Assumes 39 kkg/hr (43 s ton/hr) operating capacity.

[b] Based on 1973 cost descriptions of San Diego Plant. [c] Based on cost at Cobb County, Georgia, in 1973. Source: Personal communication, Environmental Protection Agency, Office of Solid Waste Management Programs, 1973.

TABLE 9-18
COMBINED MILLING, BALING SYSTEM - OPERATING AND MAINTENANCE COSTS[a,b]

Item		Work Week Bases, Cost ($) 5-Day/Wk	6-Day/Wk
1. Labor	Rate ($/hr)		
a) Supervisor	6.50	12,740	12,740
b) Mill Operators (1-1-0)	5.50	21,560	25,872
c) Baler Operators (2-2-0)	5.50	43,120	51,744
d) Loader Operators (1-1-0)	6.50	25,480	30,576
e) Mechanics (1-1-1)	5.50	32,340	38,808
f) Maintenance Men (1-0-1)	4.50	17,640	21,168
g) Truck Drivers (2-2-0)	5.50	43,120	51,744
h) Fill Operators (1-1-0)	6.50	25,480	30,576
		221,480	263,228
30 Percent Cost/Benefits		66,444	78,968
Subtotal		287,924	342,296
2. Electricity			
a) Mills (2) @ 373 kw		746	
b) Balers (2) @ 112 kw		224	
c) Conveyors		50	
d) Lights		40	
		1,060	1,060 (kw)
Use @ 50 Percent Capacity		x 1,715	x 2,058 (kw)
		1,817,900	2,181,480 (kwhr)
Cost @ $.015/kwhr		x .015	x .015
		27,268	32,722
3. Fuel/Oil		16,000	19,200
4. Maintenance Parts			
a) Mills[c]		38,000	45,600
b) Baler		45,000	54,000
c) Other		35,000	42,000
Subtotal		161,268	193,522
Annual Total		449,192	535,818

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[a] Assumes 49 hrs/year, 14 hrs production/day, and 8 hrs/shift.

[b] Most data modified from St. Paul annual operating costs for two five-day shifts. Costs for item 2 (d) obtained from Reinhardt and Ham, op.cit., pp104-122.

[c] Two thirds Tollemache milling value plus $3,000.

TABLE 9-19
SYSTEM SUMMARIES

Item	Baling System I	Baling System II	Mill System III	Combined Mill/Baling System IV
Major Production Equipment	(1)[a] Harris High-density charge baler with 1.9 min/bale	(1) Harris high-density charge baler with 1.9 min/bale	(3) Tollemache mills	(2) American, continuous, low-pressure, tying balers
	(2) Slat conveyor 8 foot wide	(1) Overhead crane	(6) Belt conveyors approximately 3 foot wide	(2) 500 hp direct-drive mills
	(1) Bale ejector-truck loader	(1) Bale ejector-truck loader	(2) Storage bins & truck compactor loaders	(6+) Belt conveyors approximately 3 foot wide
	(1) Large wheel loader		(1) Large wheel loader	
	(4) Flat-bed transports	(4) Flat-bed transports	(4) Enclosed, compactor transports	(4) Flat-bed transports
	(1) Large forklift	(1) Large forklift	(2) Steel-wheel loaders	(1) Large forklift
	(1) Wheel loader	(1) Wheel loader		(1) Wheel loader
Production rate	41.5 kkg/hr (45.7 s ton/hr) 31.6 bales/hr	41.5 kkg/hr (45.7 s ton/hr) 31.6 bales/hr	38.1 kkg/hr (42 s ton/hr)	39 kkg/hr (43 s ton/hr)

[a] Indicates number of equipment units.

Summaries of capital and total system costs are given in Tables 9-20 and 9-21, respectively. Table 9-21 gives costs for five-day and six-day operating work week schedules.

A summary of capital costs is given in Table 9-20. As can be seen, the largest capital expenditure was for the Harris high-density baler System I. In accordance with the EPA contract requirements a 10-year amortization period was used.

A total cost summary comparison is given in Table 9-21. As can be seen, the Harris high-density baling System II was the least costly of the four system configurations at \$4.23 per kkg (\$3.82 per s ton). System II achieved a \$0.32 per kkg (\$0.29 per s ton) savings in cost over the existing St. Paul baling plant transport and landfill operation.

The costs given in Table 9-21 are significantly lower than recorded during demonstration operation. This resulted from the following factors:

- The demonstration plants incurred extra costs due to research and development conducted during operation to refine the systems.

- Reduced labor was used for the four system cost estimates.

- Adjustments in labor hourly rates to standard rates.

The existing St. Paul baling plant, for example, was actually operating at a cost of \$6.24 per kkg (\$6.88 per ton) in late 1973. The Tollemache mill plant in Madison operated at a cost of \$3.97 per kkg (\$4.38 per ton) in early 1972. Both plants operated two shifts daily. Costs at the combined milling-baling San Diego plant were \$8.77 per kkg (\$9.67 per ton) in March 1973 on a 6-hour per day operating schedule. The high San Diego costs were due to the San Diego plant being put together in steps requiring equipment modifications which resulted in inefficient plant layout and equipment operation.

C. Comparison of Processed Solid Waste Impacts on the Landfill and the Environment.

1. Density. One benefit associated with the processing system is that is increases the density and the rate of settlement for solid waste in the landfill. The unprocessed and processed landfill densities, in terms of actual solid waste and effective in-place density (includes effect of cover soil), are given in Table 9-22. The Madison unprocessed waste densities were used because the waste composition and compaction methods were similar to the milled waste and thus provided a more valid comparison. The density of this unprocessed waste was on the high end of unprocessed landfill densities normally achieved, which were about 475 kg (800 lb) per cu yd. Since moisture contents vary by location, the most valid comparison of solid waste densities achieved between each of the four systems and unprocessed waste should have been based on actual dry weight. This dry weight was often unavailable. The System IV combined milled-low-pressure baled waste had the highest wet or total weight density. The derivation of the noted density values given in the San Diego project report was based on the total landfill volume plus soil excavation and less soil cover quantities. Final volumes were determined by surveying, but no indication was given of how soil quantities were measured.

TABLE 9-20
AMORTIZATION SUMMARY

System	Harris System 1	Harris System II	Mill System III	Combined Mill/Baling System IV
Construction cost ($)	2,150,000	1,950,000	1,690,000	1,607,000
Capital Recovery factor, over 10 years with zero value after 10 years, at 7 percent compounded interest	0.1424	0.1424	0.1424	0.1424
Annual Capital Recovery ($)	306,000	278,000	241,000	229,000

TABLE 9 - 21
COST SUMMARY
TRANSFER, PROCESSING, TRANSPORTING AND LANDFILLING[a]

Item	Baling System I		Baling System II		Mill System III		Combined Mill Baling System IV	
	5[e]	6[e]	5	6	5	6	5	6
Annual Production:[a]								
Wet kkg	142	171	142	171	131	157	134	161
Dry kkg[c]	103	124	103	124	95	114	97	117
Wet s ton	157	188	157	188	144	173	147	177
Dry s ton[c]	114	136	114	136	104	125	106	128
Bales	108	130	108	130	None	None	NA[d]	NA
Annual Cost ($1000s):								
Amortization	306	306	278	278	241	241	229	229
Operating & Maintenance	368	439	347	413	400	476	449	536
Total	674	745	625	691	641	641	678	765
Unit Cost ($):								
Per wet kkg	4.75	4.19	4.23	3.89	4.73	4.43	4.90	4.62
Per dry kkg	6.54	5.78	5.83	5.37	6.52	6.10	6.77	6.36
Per wet s ton	4.29	3.81	3.82	3.54	4.30	4.02	4.47	4.20
Per dry s ton	5.91	5.27	5.26	4.90	5.95	5.56	6.20	5.81
Per bale	6.24	5.52	5.56	5.12	None	None	NA	NA

[a] See Table 9-19 for details of systems.

[b] Based on 14 production hours per day, 49 weeks per year.

[c] Based on 27.6 percent of weight water content.

[d] NA = not available.

[e] Number of days/week in operation.

TABLE 9 -22
WASTE DENSITIES

Method	Solid Waste Densities: kg/cu m (lb/cu yd)					
	Actual Density of Solid Waste[a]		Effective Landfill Density[c]		Actual Density of Bales	
	Wet Wt.	Dry Wt.[b]	Wet Wt.	Dry Wt.[b]	Wet Wt.	Dry Wt.[b]
Normal landfill: Unprocessed[d]	560-380 (950-640)	410-275 (690-465)	410-260 (690-440)	295-190 (500-320)	NA	NA
Systems I and II: Harris baled[e]	875-685 (1680-1160)	640-495 (1225-840)	840-655 (1610-1110)	615-480 (1180-815)	930-725 (1782-1225)	685-525 (1310-890)
System III: Tollemache milled[d]	670-450 (1130-760)	420-280 (710-480)	630-425 (1070-720)	460-305 (775-520)	NA	NA
System IV: Combined milled/ baled[f]	890-920 (1510-1400)	630-580 (1070-985)	675-625 (1137-1054)	490-455 (825-765)	1055-975 (1790-1655)	755-695 (1280-1180)

[a] Actual density refers to as-placed compacted density for a single fill lift and does not include effects of additional compaction from vehicles travelling over completed fill lifts or from the weight of top layers in deep landfills.

[b] At 38.1 percent moisture content on a dry weight basis.

[c] Includes the effects of cover soil as given by:

$$\text{Eff. Density} = \frac{\text{Wt. Solid Waste}}{\text{Vol. Solid Waste + Volume Cover Soil}}.$$

TABLE 9-22 (Cont.)

[d] Reference: Final Report on a Demonstration Project at Madison, Wisconsin to Investigate Milling of Solid Wastes, Between 1966 and 1972. Volume 1, John J. Reinhardt and Robert K. Ham, EPA Office of Solid Waste Management Programs, p. 43.

[e] St. Paul measurements with no space between bales and with space between bales assumed to be the same as on top tier. Six inches of cover soil are used to cover each lift of three bales high.

[f] Reference: Attachment VII, Refuse Baling Equipment Technical Evaluation, In Place Density Bale Fill, City of San Diego, June 8, 1973.

On a dry weight effective landfill density basis, Systems I and II high-density baling averaged the highest density.

Density in a bale landfill can be increased by improving the placement of bales or producing more regular bales (such as San Diego) to eliminate spaces between bales which reduce the in-situ density. The extensive compaction by equipment of the landfilled milled solid waste may have contributed to the reported high density. Heavy compaction in a landfill of raw refuse will also give excellent densification. However, there are improvements in average effective dry weight densities of mill processed over unprocessed solid waste. The increase in processed over unprocessed landfill densification is presented as follows: Systems I and II, high density baling - 60 percent; System III, milled - 4 percent; and System IV, milled/baled - 53 percent.

2. Landfill Operations. Baled solid waste required no spreading, and less transport volume and landfill handling than either unprocessed or milled waste. The bales were placed onto and from transport trucks and located directly into the working face of the fill. Milled waste required compaction, and the degree of compaction will affect the in-situ density. Since compaction is not required for bale landfills, less equipment (no compactors) is required.

The Madison project final report included the assessment that daily cover soil was not needed for milled solid waste. Operation of a sanitary landfill would by definition require daily soil covering. Thus, the cover soil requirements for milled waste would be similar to unprocessed waste less the savings due to increased density. It should be noted that bale working faces are vertical and 3 m (10 ft) or more in minimum height; thus only the top horizontal surface is covered daily. Unprocessed and milled waste are normally placed on a slope in 90 to 120 cm (3 to 4 ft) layers; therefore, soil must be placed on both horizontal and sloped surfaces which must be covered with 15 cm (6 in) of clean earth daily. Thus, baled waste should require less soil cover than comparable processing on a lb per lb basis.

Observations at the St. Paul bale landfill during wet weather indicated no impediment of mobile equipment operations occurred during heavy rainfalls. Wheeled transport trucks and landfill equipment were well supported by the solid bale surfaces, even when the vehicle wheels sank through the 15 cm (6 in) cover soil. It was reported in the Madison project that wheeled vehicles could travel satisfactorily on the milled waste due to its compact, uniform surface. Wet weather travel was difficult to impossible in unprocessed waste landfills based on typical observations.

3. Environmental Impact. Less wind-blown litter was observed at the St. Paul bale landfill than at normal unprocessed waste landfills. Madison milled waste landfill litter was also reported as less than for unprocessed waste, but litter fences were required at Madison to catch plastic film, etc. In the case of the bales, the reduced surface area of in-situ waste and the adherence of materials within the bales produced the low litter level.

The American Hoist and Derrick Company stated that no fires had occurred at the balefill during its two years of operation from 1971 to July 1973. During the twelve month period between the first field survey of the bale landfill (July 1973) and the end of the bale landfill monitoring (June 1974), no fires were reported or observed in the bale landfill. During the same twelve month period,several fires were reported, and one was observed by our staff at a private (Phoenix) landfill, located about one mile from the bale landfill, that received normal unprocessed solid waste. The Phoenix landfill received the same type of waste as the bale landfill, some of which was delivered by St. Paul private collectors who did not want to pay the baling plant fee. Although the twelve month period of record is relatively short, the similarity in solid wastes and identical climate at the bale landfill and Phoenix landfill indicate the possibility that the bales were a factor in reducing the incidence of fires.

The concentrations of various constituents found in the St. Paul bale test cell leachate were generally less than or in the low end of the range of concentrations for leachate from normal and shredded waste landfills (see Table 10-5). The relatively short period of leachate monitoring may not represent long-term trends.

SECTION 10

SIMULATION OF BALE SANITARY LANDFILL IN A TEST CELL

A. Purpose.

Evaluation of the bale sanitary landfill under controlled conditions was conducted in a test cell constructed at the American Solid Waste Systems division of American Hoist and Derrick Company landfill. The test cell was constructed to permit monitoring and sampling of gas composition, leachate quantity and quality, settlement, and temperature. The test cell construction commenced on August 2, 1973, and was completed on October 5, 1973. The baseline monitoring began on September 27, 1973, and continued until November 30, 1974.

B. Method of Study.

1. Site Location. The test cell was constructed at the edge of the American Hoist bale landfill about 12 miles from the bale plant (see Figure D10, Vol. 2). The location of the test cell at the bale landfill is shown in Figure D11, Vol. 2. The area under the test cell was filled with three layers of bales and covered with six to eight inches of soil. Water drains away from the test cell to the north, east, and west over the the edge of the fill area toward the Rock Island Railroad tracks. The cell is exposed to wind and other normal weather conditions. Access to the cell is via the landfill access road onto the filled area and up a ramp on the south side of the cell (see Figure D11, Vol. 2).

2. Test Cell Design and Construction. The test cell design is shown in Figure 10-1. The inside dimensions of the test cell were 30 by 33 meters in area and 5 meters in height. The cell walls were constructed of solid waste bales to more closely simulate the normal bale landfill environment. The cell height of three bales is the same as the balefill height. The leachate collection sump was located 3 feet outside of the northwest corner of the north cell wall to prevent damage during placement of bales in the cell. The sump was installed after filling the cell.

Test cell construction consisted of several steps (see Photograph 10-1):

a. Grading. Initial grading of the test cell area provided a level base for the cell walls and bottom.

b. Cell Walls. Three walls were built with bales as shown in Figure 10-2: the east, west, and south walls. The north side was left open to provide access for the forklift to place bales in the cell.

c. Cell Bottom. The bottom of the cell was filled with clean sandy clay soil of 15 to 46 cm thickness, graded with a one percent slope downward toward the northwest corner for leachate collection. Three trenches were cut in the cell bottom converging on the leachate sump. The trenches were cut into the cell bottom with a dozer

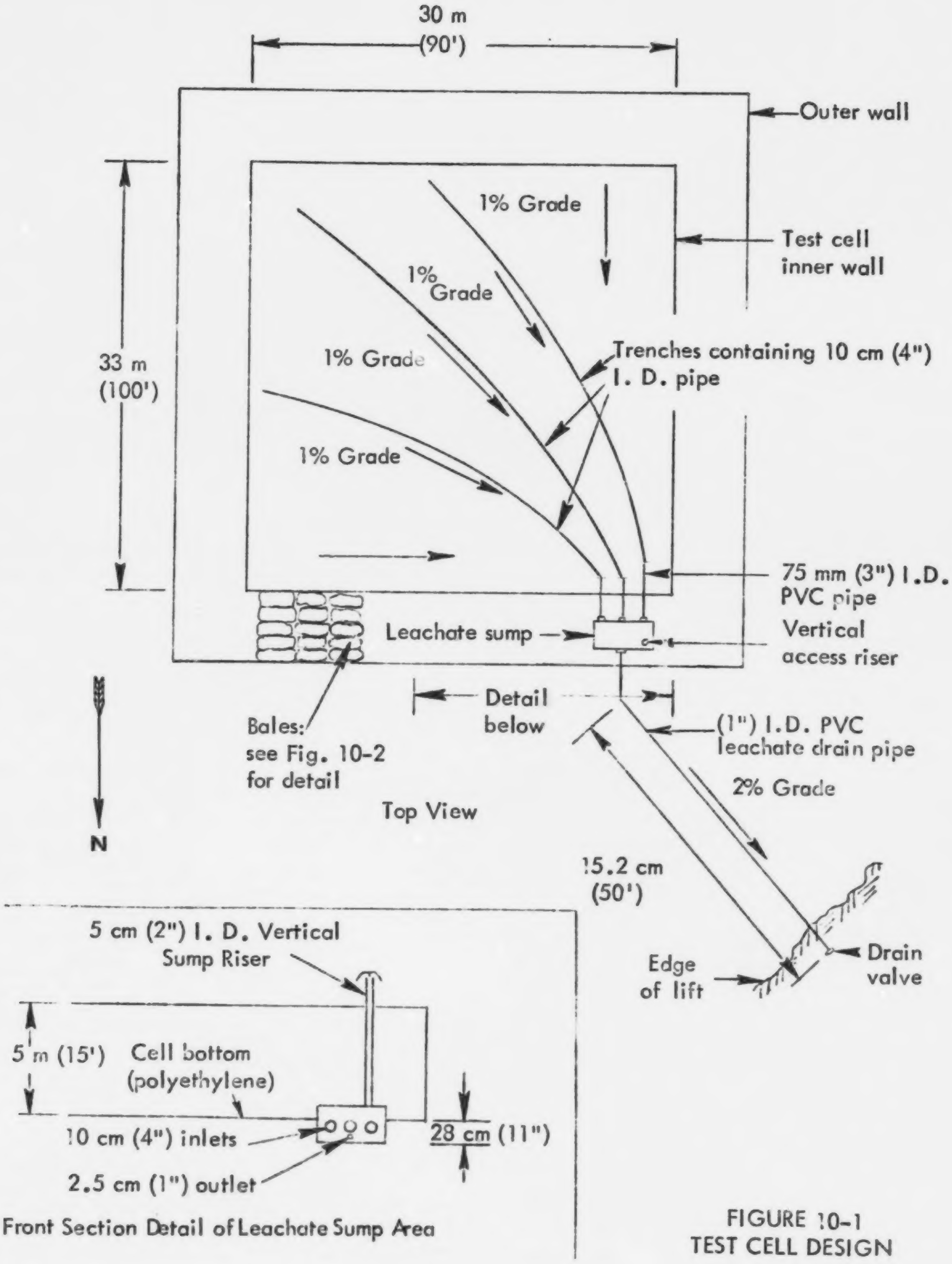
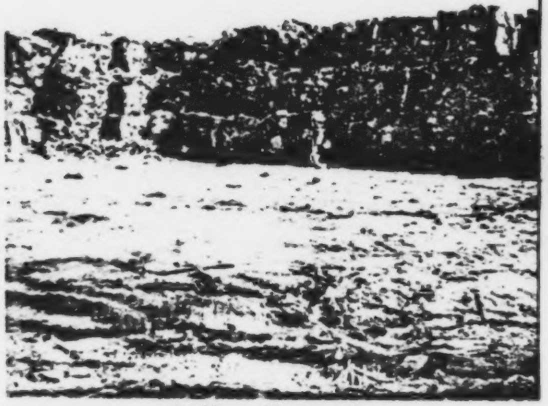
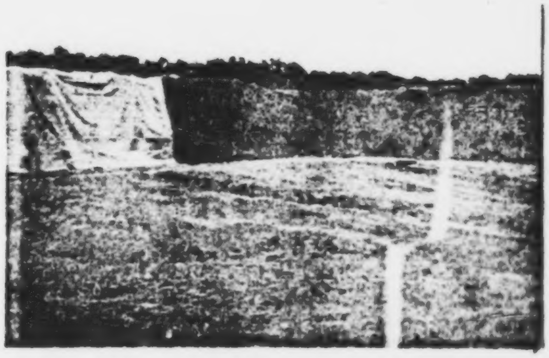

30 m
(90')
Outer wall
Test cell
inner wall
33 m
(100')
1% Grade
1% Grade
1% Grade
1% Grade
Trenches containing 10 cm (4")
I. D. pipe
75 mm (3") I.D.
PVC pipe
Leachate sump
Vertical
access riser
Bales:
see Fig. 10-2
for detail
Detail
below
(1") I.D. PVC
leachate drain pipe
2% Grade
N
Top View
15.2 cm
(50')
Edge
of lift
Drain
valve
5 cm (2") I. D. Vertical
Sump Riser
5 m (15')
Cell bottom
(polyethylene)
10 cm (4") inlets
2.5 cm (1") outlet
28 cm (11")
Front Section Detail of Leachate Sump Area

FIGURE 10-1
TEST CELL DESIGN

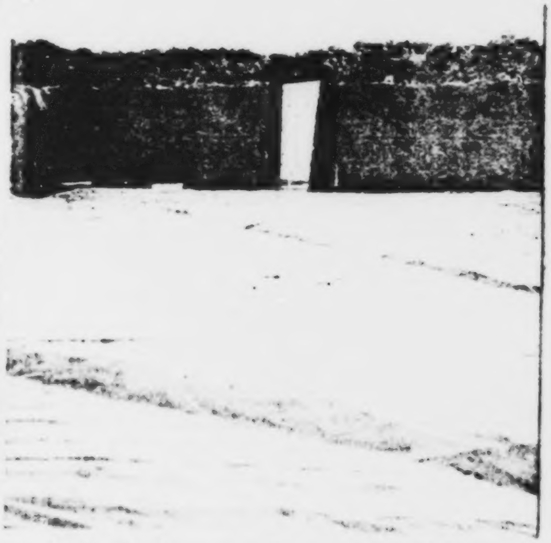


a. Cell walls in place

b. Polyethylene membrane on cell walls

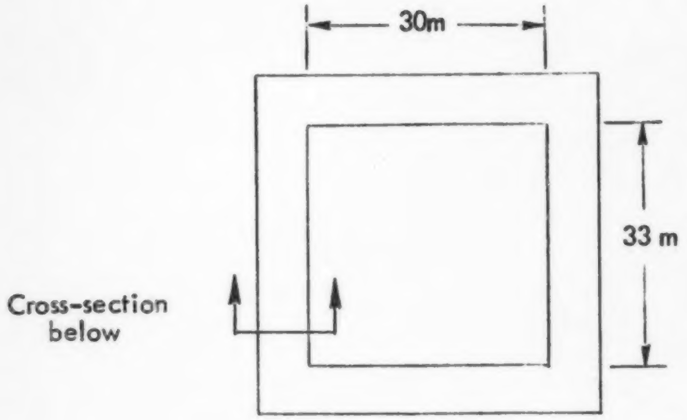


c. Protective layer of roofing paper on polyethylene membrane

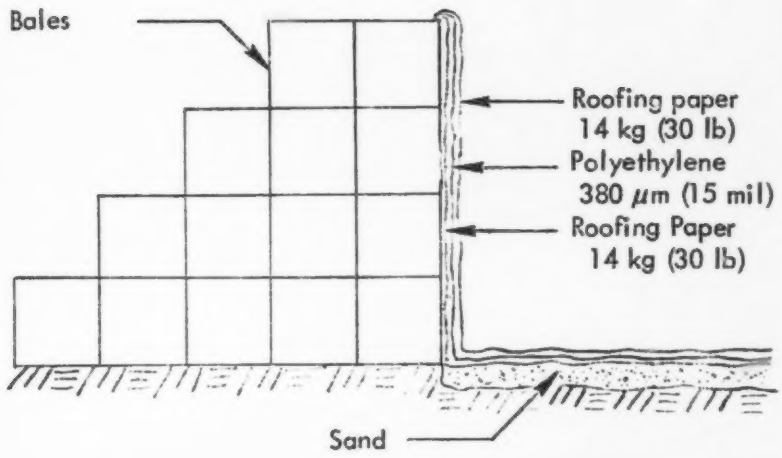


d. Polyethylene membrane on cell bottom showing leachate drain pipe trenches

PHOTOGRAPH 10-1
TEST CELL CONSTRUCTION


30m
33 m
Cross-section
below

Top View


Bales
Roofing paper
14 kg (30 lb)
Polyethylene
380 µm (15 mil)
Roofing Paper
14 kg (30 lb)
Sand

Section View

FIGURE 10-2

TEST CELL WALL
CONFIGURATION

Not to Scale

blade beginning at grade and reaching a constant depth of 15 cm (six inches) below grade to protect the leachate drain pipe. The trenches were about 40 cm wide and had an additional one percent slope toward the northwest corner of the cell. The bottom of the cell was cleaned of loose rock and other items that might possibly puncture the polyethylene membrane by hand-raking and carrying off the detritus with a "bobcat" loader.

d. Polyethylene Membrane Installation. A layer of 30-lb roofing felt was hung vertically along the three walls by nailing into the top bales. The 1-m wide felt was cut into 4 m lengths and overlapped to protect the polyethylene. Two layers of 15-mil polyethylene, 4.4 m wide and 31 m long were suspended along each wall by nailing slats to the membrane edge and driving 10 cm nails into the top bales in front of the slats to support them. A second layer of roofing felt was then hung from the walls over the membrane. Scrap roofing felt strips were placed in the trenches to protect the membrane. The bottom membranes were placed using 2 layers of 15 mil, 4.4 m by 34 m polyethylene strips overlapped 0.3 to 0.5 m. All seams were sealed with a 15 cm wide layer of "Henry" brand latex sealant and then taped with 10 cm wide waterproof industrial tape. The fourth wall was completed after the cell was filled using the same technique as for the first three walls.

e. Leachate Collection System. A 10 cm diameter flexible, perforated plastic pipe was laid in each of the three trenches and subsequently connected to three 10 cm PVC pipes which were connected to the leachate sump (see Photograph 10-2a). The trenches were filled with 1 cm smooth gravel to protect the perforated pipe. A 60 cm layer of clean, washed sand was placed on the polyethylene membrane and graded level for placing bales.

f. Cell Filling. The cell was filled with eight days' production of bales using the existing forklift placement method. The total number of bales placed in the test cell was 1,542, which weighed a total of 1.98 million kg (2,179 tons). Probes for monitoring temperature, settlement and gas (Photograph 10-2b) were placed at five stations during the placement of bales. The test cell probe locations are shown in the top view of Figure 10-3.

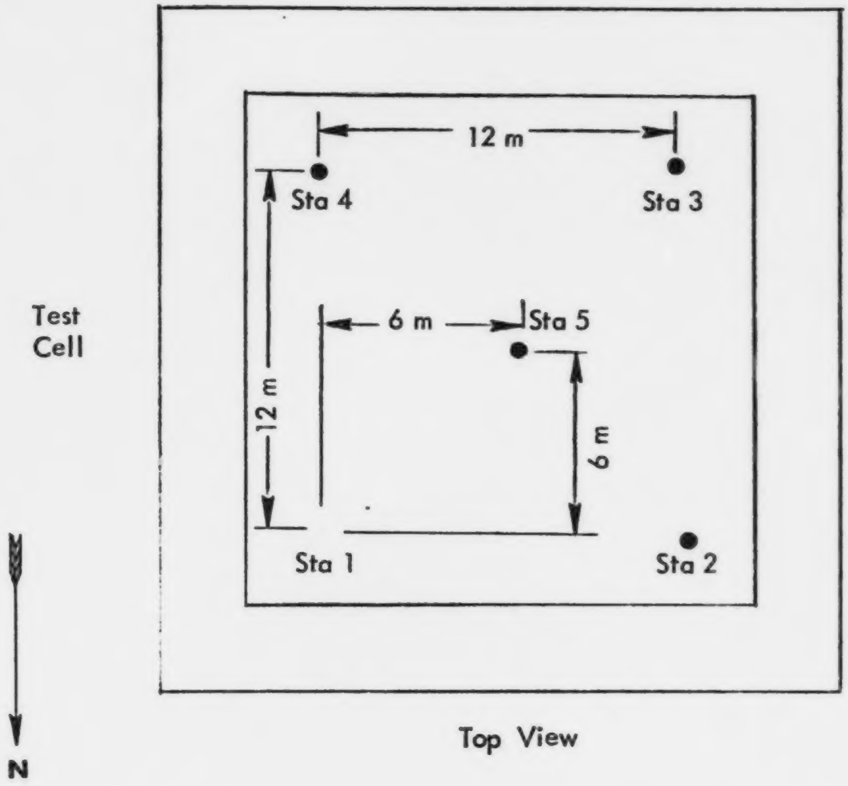
g. Completion of the Cell. The final membrane section and roofing felt protection was placed on the exposed north wall of the bales in the test cell. The leachate collection sump, a 38 long by 30 wide by 20 deep cm box with lid, was placed about 1 m outside the wall in an excavation. The three perforated plastic leachate collection pipes were epoxy-cemented to three 10 cm PVC pipe extensions, and then the PVC pipes were epoxy-cemented to three pipe collar openings in the sump box. The polyethylene membrane was sealed around the three leachate collector pipes at their juncture with the extensions to the sump box using the latex adhesive and industrial tape previously described. A 5 cm I. D. PVC pipe was fitted to the sump box top and extended vertically a height of 4 m to protrude 1 m above the top surface of the bales. This access pipe was provided as a backup to allow the sump to be pumped empty. A 2.5 cm I. D. PVC pipe was installed in a ditch extending from the sump north to the edge of the fill at a two degree slope to drain leachate from the sump. A PVC cap was placed on the vertical user access pipe, and a PVC ball valve was placed on the end of the

a. Leachate collection sump and drain pipes b. Monitoring probes in filled cell

c. View of filled cell

d. Completed cell with soil cover and access ramp

PHOTOGRAPH 10-2
TEST CELL INSTALLATIONS


12 m
Sta 4
Sta 3
Test
Cell
6 m
Sta 5
12 m
6 m
Sta 1
Sta 2
N
Top View

No Scale

FIGURE 10-3

TEST CELL PROBE LOCATIONS

leachate drain pipe. A 7.6 cm I.D. cast iron sewer pipe was placed around the leachate drain pipe for protection from vehicles, and the pipe was covered with 20 cm of soil. The fourth (north) cell bale wall was placed. An access ramp was constructed and a 15 to 60 cm cover soil layer was placed on the cell, the varying depth resulting from variations in bale size. The walls were covered with soil for aesthetic purposes, and a 30 cm soil berm was built along the outside edge of the test cell membrane wall. The berm retained water from rain or snow falling on the cell. The purpose of the berm was to allow direct correlation between precipitation data and the amount of water that fell and remained on the cell. This eliminated the need to estimate any runoff. The completed test cell is shown in Photograph 10-3. Cell construction was completed October 3, 1973.

3. Test Cell Probe Configurations. Five test cell monitoring stations were located as shown in Figure 10-3. A rain gauge was located near Station 5. The center station contained only settlement plates and risers (same as Item C below); each of the other four stations contained all of the probes listed below. The probes in Items a, b, and c were installed during test cell construction and the lysimeters of Item d at a later time.

a. Gas Probes. Two 1.1 cm I.D. polyethylene tubes at 0.9 m and 2.4 m depths were perforated at the bottom and used for gas monitoring (see Figure 10-4).

b. Temperature Probes. Three capped 2.5 cm I.D. PVC tubes at depths of 0.6, 1.5, and 2.4 meters were used for housing thermistors. An additional 2.5 cm I.D. PVC tube at 2.4 m was used for backup temperature monitoring by thermometers.

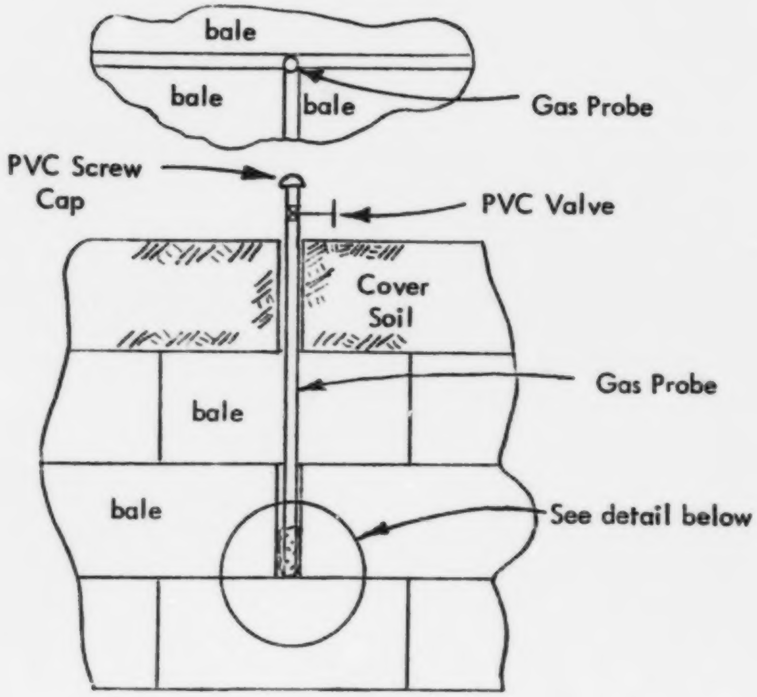
c. Settlement. Three 0.7 x 0.7 meter metal settlement plates were located below the bottom bale, between the middle and bottom bales, and between the top and middle bales. Vertical risers of 2 cm I.D. galvanized cast iron pipe were connected to each plate and rose about 1 m above the test cell cover soil. Concrete block surface benchmarks were placed on top of the top bales at each of the five settlement probes.

d. Lysimeters. In addition to the station probes, 16 lysimeters (soil leachate sampling devices) were installed in the test cell during the period from February 26 through March 10, 1974. The lysimeters were placed at four depths, 0.3, 0.8 or 0.9, 1.4 or 1.5, and 2.3 meters at each of Stations 1 through 4. Variations in depth of about 1 meter (0.8 and 0.9, 1.4 and 1.5) occurred at several probes due to restrictions encountered during placement. One lysimeter was inserted to a depth of 3.4 meters.

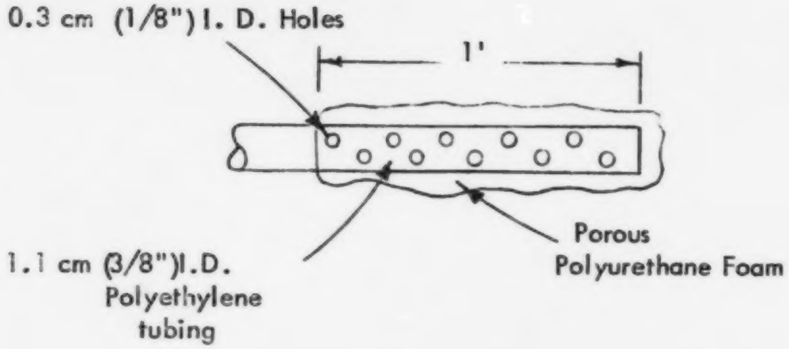
4. Core Holes. Five holes, 15 cm in diameter, were augered on November 19, 1974, to sample solid waste for biodegradation, moisture and organic content, and temperature: two at Stations 1 and 3, one in the most recently completed area (filled June 1974), and two in an older landfill area (filled mid-1972).

5. Test Cell Monitoring. Table 10-1 outlines the test cell monitoring schedule. Photograph 10-2 illustrates monitoring devices. Sampling and monitoring procedures and data forms are given in Appendix E. Laboratory analytical methods are given in Table 10-2. A brief summary of the methods is given below. All analyses were performed in the Ralph Stone and Company laboratory in Los Angeles, California. Samples were shipped to Los Angeles by air on the day they were taken and analyzed the next day.

PHOTOGRAPH 10-3
COMPLETED TEST CELL


bale
bale
bale
Gas Probe
PVC Screw Cap
PVC Valve
Cover Soil
Gas Probe
bale
bale
See detail below

Side View


0.3 cm (1/8") I. D. Holes
1'
1.1 cm (3/8")I.D. Polyethylene tubing
Porous Polyurethane Foam

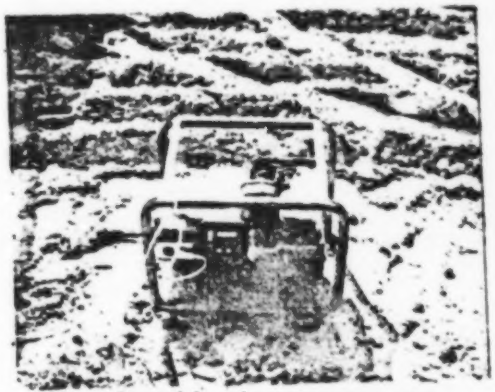
Gas Probe Detail

Not to scale.

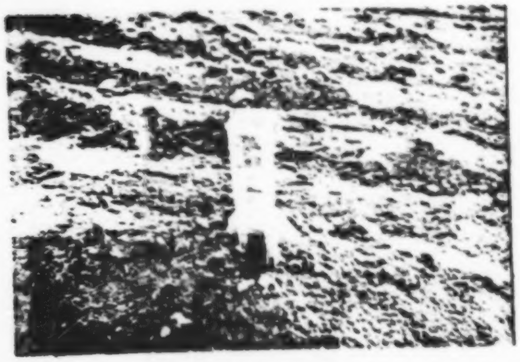
FIGURE 10-4
TEST CELL
GAS PROBE

a. Gas sampling, temperature and settlement probes, and leachate sump access in place

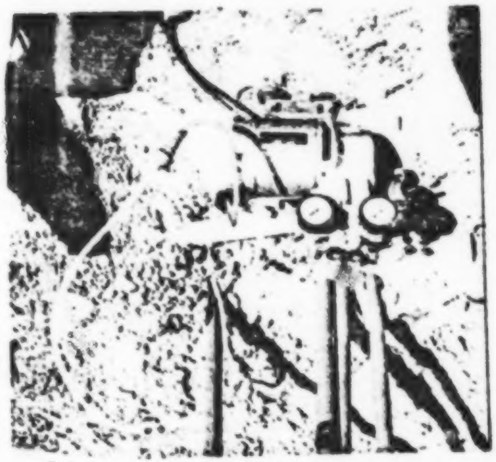
b. Sampling station



c. Portable electric generator



d. Rain gauge



e. Gas sampling apparatus

PHOTOGRAPH 10-4
TEST CELL MONITORING

TABLE 10-1

BALE TEST CELL MONITORING SCHEDULE

Monitoring Parameter	Frequency	Constituent or Units
Gas	Weekly	Samples analyzed for: CH_4, CO_2, N_2, O_2, H_2S, CO.
Temperature	Daily during the first two weeks, weekly thereafter.	Measured in degrees centigrade.
Settlement	Weekly	Feet
Leachate from sump	Weekly	Quantity, liters.
	Weekly	Samples analyzed for: pH, total coliforms, fecal coliform, BOD_5, Cl^-, $SO_4^{=}$, sulfides, TDS, NO_3, NH_3^-, Org - N.
	Annually	Composite of weekly samples analyzed for: Al, As, Ba, Ca, Cd, Cr, Cu, F^-, Fe, Hg, Mg, Mn, Ni, Pb, Zn.
Lysimeter Moisture	Weekly	Quantity, liters.
	Weekly	Samples analyzed for: pH, total coliforms, fecal coliforms, BOD_5, Cl^-, $SO_4^{=}$, S sulfides, TDS, NO_3^-, NH_3, Org-N.
Core Sampling	Once (11/19/74)	Samples analyzed for organic content, temperature, moisture content, decomposition.

TABLE 10-2
ANALYTICAL METHODS

Parameter	Analytical Method	Reference
LEACHATE		
Biochemical Oxygen Demand (BOD)	Manometric BOD_5	Hach Manometric BOD Apparatus, Hach Chemical Co. (p. 2)
Total Coliform	Standard MPN tests, multiple-tube procedures	*Standard Methods,* 13th ed. 1971 (p. 664)
Fecal Coliform	Standard MPN, multiple-tube procedure	*ibid.* (p. 669)
Nitrate Nitrogen	Brucine Method	*ibid.* (p. 461)
Sulfate	Turbidimetric	*ibid.* (p. 334)
pH	Electrometric	*ibid.* (p. 500)
Total Dissolved Solids	Filtrable Residue (Difference Method)	*ibid.* (p. 539)
Chloride	Mercuric Nitrate Titration	*ibid.* (. 97)
Organic Nitrogen	$H_2SO_4/K_2SO_4/HgO$ Digestion, Titration	*ibid.* (P. 469)
Ammonia Nitrogen	Distillation, Titration	*ibid.* (p. 222)
Sulfides	Methylene Blue colorimetric	*ibid.* (p. 551)
GAS ANALYSES		
CH_4, CO_2, O_2, N_2	Gas-solid Chromatography (Silica gel/molecular sieves dual columns) Varian Model A90-P3.	*1970 Annual Book of ASTM Standards, Part 23, 1970* (after p. 934)
SOLID WASTE AND CORE SAMPLES		
Organic Content (Total Organics)	Volatile Residue (percent)	*Standard Methods,* (p. 540)

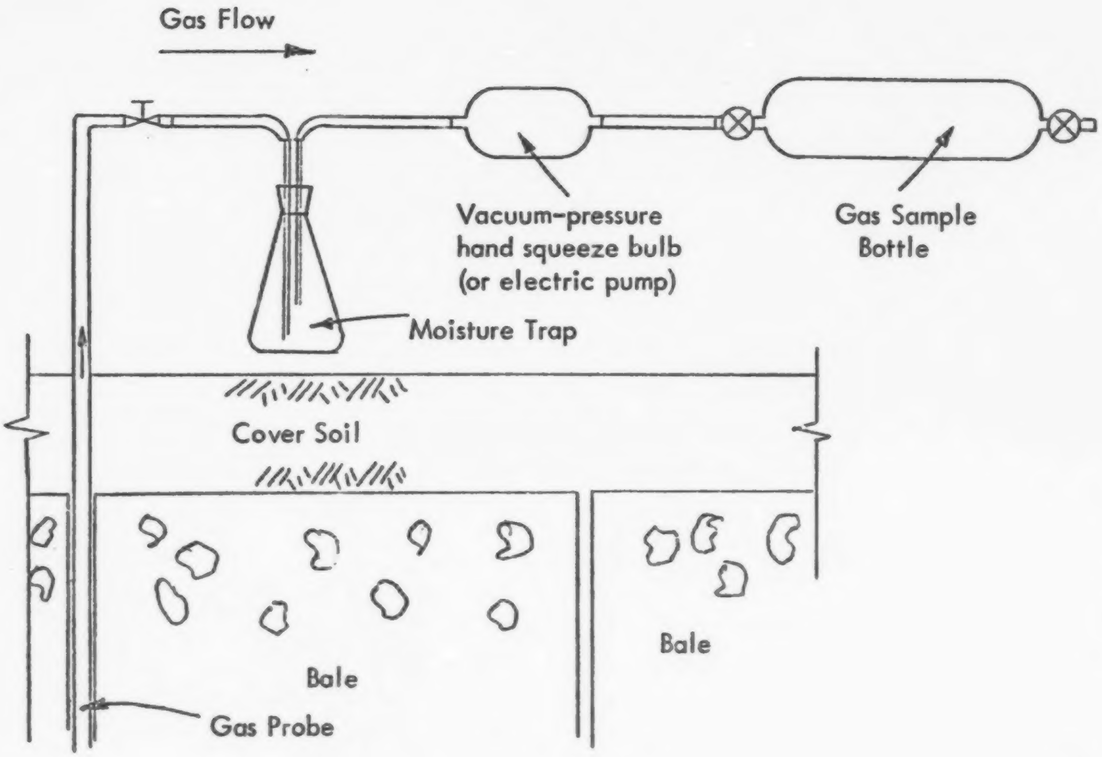
a. Gas Sampling. An illustration of the gas sampling apparatus appears in Figure 10-5. A portable generator was used to operate the electric pump. A hand sampling pump was used as a backup for times when snow or mud prohibited automobile access to the test cell, or when the generator malfunctioned. Separate on-site testing for hydrogen sulfide was conducted using a calibrated volume-flow hand pump and H_2S detectors manufactured by Mine Safety Appliances (MSA) Company. The H_2S concentrations were also checked on the laboratory gas chromatograph during gas analyses.

Basically, the procedure consisted of evacuating a 250- or 500-ml sample bottle and connecting it to the test cell gas sample probe as shown in Figure 10-5. Prior to sampling, the probe valve was opened, the probe and evacuated bottle were purged by running the vacuum pump for at least one minute so that about 2,500 ml of sample gas passed through. The bottle was then pressurized by additional pumping with the downstream bottle valve closed, and the upstream valve was closed when about 10 psi of pressure in the sample was read on the pump gauge.

b. Temperature. Two methods of temperature measurement were used. Stainless steel thermistors and a telethermometer manufactured by Yellow Spring Instruments Company were inserted in the 0.6, 1.5 and 2.4 meter deep probes for primary temperature measurement. Since problems had been encountered with instruments and thermisters on previous landfill monitoring projects, a thermometer backup system was provided. The backup system consisted of lowering a thermometer in a test tube filled with water to the bottom of each temperature probe by means of a string and leaving it there for about 15 minutes so that the water temperature stabilized to the test cell temperature. The test tube-thermometer was then raised, and the temperature reading was taken immediately.

c. Settlement. Twenty settlement monitoring points existed: three plates with risers, and one concrete surface benchmark at each of five stations. Four permanent benchmarks placed in strategic locations near the test cell were used as fixed reference elevation points to check the test cell plate risers and benchmark elevations. Although only one reference benchmark was needed, the extra benchmarks were installed in case one was inadvertently destroyed. A surveyor's level, at a known elevation, was used to read the test cell plate risers and concrete surface benchmark elevations on a surveyor's rod. Since the test cell was constructed on an area previously filled with bales, the relative change in elevations between the settlement risers beneath the three bale layers and the surface benchmark were used to determine the differential and total settlement.

d. Sump Leachate. Leachate samples were taken in one-liter polyethylene sample bottles (one liter samples were taken if enough leachate was present). The volume of leachate was determined for small (up to 15-liter) quantities by filling a 19-liter (5-gallon) graduated container or the one-liter sample bottles. For larger quantities, the leachate was drained into the 19-liter graduated bucket for one minute to determine the flowrate. The drain was left open and the flowrate checked periodically until the flow ceased. The time-averaged flowrate was used to determine the total volume of


Gas Flow
Vacuum-pressure hand squeeze bulb (or electric pump)
Gas Sample Bottle
Moisture Trap
Cover Soil
Bale
Bale
Gas Probe

No Scale

FIGURE 10-5
GAS SAMPLING
APPARATUS

leachate. Samples were taken from the filled container at different times during flow so that a representative sample would be analyzed. During cold weather, when the exposed leachate drain valve and leachate were frozen, leachate was monitored through the vertical access pipe using a vacuum pump and tube to withdraw a sample.

e. Lysimeter Monitoring. Soil water lysimeters were sampled using a vacuum hand pump. The quantity of leachate withdrawn was measured and samples analyzed as indicated in Table 10-2.

f. Core Sampling. Core sampling was undertaken at the test cell, the newest landfill area, and the oldest landfill area. Temperature, decomposition, organic content, and moisture content were determined for the samples. In the test cell, the auger drill sampling was in the top 0.2 meters of bales and at 1.83 m, 2.75 m, and 3.36 m depths. The 3.36 m depth was determined to be the deepest that could be reached and still provide a margin of safety to avoid penetrating the polyethylene liner. At the new and old landfill areas, the drilling continued until bottom soil or intermediate lift soil was reached. Samples were taken from the top 0.2 m of the top bales, and at two intermediate depths.

C. Results and Discussion.

When the field test cell was completed, it was monitored at least once each week for 14 months, except that temperature was monitored daily during the first 14 days.

1. Leachate.

a. Sump Leachate Quantity. During the period from November 7, 1973, through mid-September, 1974, cumulative rainfall on the test cell was 56.13 cm (22.1 in.), which was equal to about 490,000 liters over the test cell surface area. The days on which rainfall occurred, the quantity of rain and the daily quantity and cumulative total volume of rainfall entering the test cell are summarized in Table 10-3.

The daily sump leachate flows are shown in Figure 10-6. Leachate flowrates were level during each period they occurred. Sump leachate exceeding one liter per day was initially observed June 1, 1974, about 250 days after filling the cell. This was attributed to the cell accumulating moisture to the point of saturation, and frozen ground during the winter months which created a barrier to moisture entry.

The leachate and precipitation trends are plotted on Figure 10-7. As can be seen, leachate began to be obtained in mid-March in very small quantities, usually less than 1 liter per day. Leachate flow increased during June 1 to August 27, 1974, and then became negligible (less than one liter per day) in September.

A mass balance evaluation of moisture conditions at the test cell was completed as follows. The factors involved in moisture behavior in the test cell are expressed in the equation:

TABLE 10-3
TEST CELL PRECIPITATION

Month	Date	Days Since Filled	Rainfall, cm (in.)		Precipitation Per Event (Liters)	Cumulative (liters)
1973						
Nov.	7	40	.15	(0.06)	1,278	1,278
	20	53	4.78	(1.88)	40,042	41,320
	21	54	1.02	(.4)	8,520	49,840
	24	57	.36	(.14)	2,982	52,822
	26	59	.30	(.12)	2,556	55,378
Dec.	5	68	.61	(.24)	5,112	60,490
	9	72	2.03	(.08)	1,704	62,194
	14	77	.15	(.06)	1,278	63,472
	15	78	.41	(.16)	3,408	66,880
	23	86	.71	(.28)	5,964	72.844
	24	87	.71	(.28)	5,964	78,808
	26	89	.46	(.18)	3,834	82,642
1974	27	90	.51	(.20)	4,259	86,901
Jan.	9	103	.15	(.06)	1,278	88,179
	20	114	.41	(.16)	3,408	91,587
Feb.	1	126	.05	(.02)	426	92,013
	2	127	.56	(.22)	4,686	96,699
	3	128	.30	(.12)	2,556	99,255
	4	129	.05	(.02)	426	99,681
	5	130	.91	(.36)	7,668	107,349
	14	139	1.02	(.04)	852	108,201
	16	141	2.03	(.08)	1,704	109,905
Mar.	8	161	.05	(.02)	426	110,331
	14	167	.25	(.10)	2,130	112,461
	15	168	.51	(.2)	4,259	116,720
	22	175	.15	(.06)	1,278	117,998
	26	179	.76	(.3)	6,390	124,388
	29	182	.25	(.1)	2,130	126,518
	30	183	.25	(.1)	2,130	128,648
	31	184	.86	(.34)	7,242	135,890
Apr.	11	195	.30	(.12)	2,556	138,446
	12	196	.97	(.38)	8,094	146,540
	13	197	.30	(.12)	2,556	149,096
	22	206	.10	(.04)	852	149,948
	27	211	.81	(.32)	6,816	156,764
May	3	217	.15	(.06)	1,278	158,042

TABLE 10-3
TEST CELL PRECIPITATION
(Cont.)

Month	Date	Days Since Filled	Rainfall, cm	(in.)	Precipitation Per Event (liters)	Cumulative (liters)
1974						
May	7	221	.46	(.18)	3,833	161,875
	8	222	.56	(.22)	4,686	166,561
	9	223	.56	(.22)	4,686	171,247
	10	224	2.48	(.98)	20,873	192,120
	12	226	1.57	(.62)	13,205	205,325
	14	228	.56	(.22)	4,686	210,011
	16	230	.25	(.10)	21,299	231,310
	18	232	.25	(.10)	2,130	233,440
	22	236	.51	(.20)	4,260	237,700
June	2	247	1.52	(.60)	12,779	250,479
	3	248	.36	(.14)	2,982	253,461
	4	249	4.52	(1.78)	37,912	291,373
	6	251	1.22	(.48)	10,224	301,597
	9	254	.86	(.34)	7,242	308,839
	10	255	3.96	(1.56)	33,226	342,065
	13	258	.25	(.10)	2,130	344,195
	19	264	.41	(.16)	3,408	347,603
	20	265	1.47	(.58)	12,353	359,956
	21	266	.81	(.32)	6,816	366,772
July	1	276	.05	(.02)	426	367,198
	3	278	.15	(.06)	1,278	368,476
	10	285	.30	(.12)	2,556	371,032
	12	287	.76	(.30)	6,390	377,422
	18	293	.15	(.06)	1,278	378,700
	24	299	2.18	(.86)	18,317	397,017
Aug.	2	308	3.15	(1.24)	26,411	423,428
	3	309	4.83	(1.90)	40,468	463,896
	4	310	.05	(.02)	426	464,322
	10	316	.41	(.16)	3,408	467,730
	21	327	.61	(.24)	5,112	472,842
Sept.	6	343	.15	(.06)	1,278	474,120
	9	346	.61	(.24)	5,112	479,232
	10	347	.25	(.10)	2,130	481,362
	12	349	1.02	(.40)	8,520	489,882
Total			56.13	(22.10)		

NOTE: Leachate flow stopped August 27, 1975.

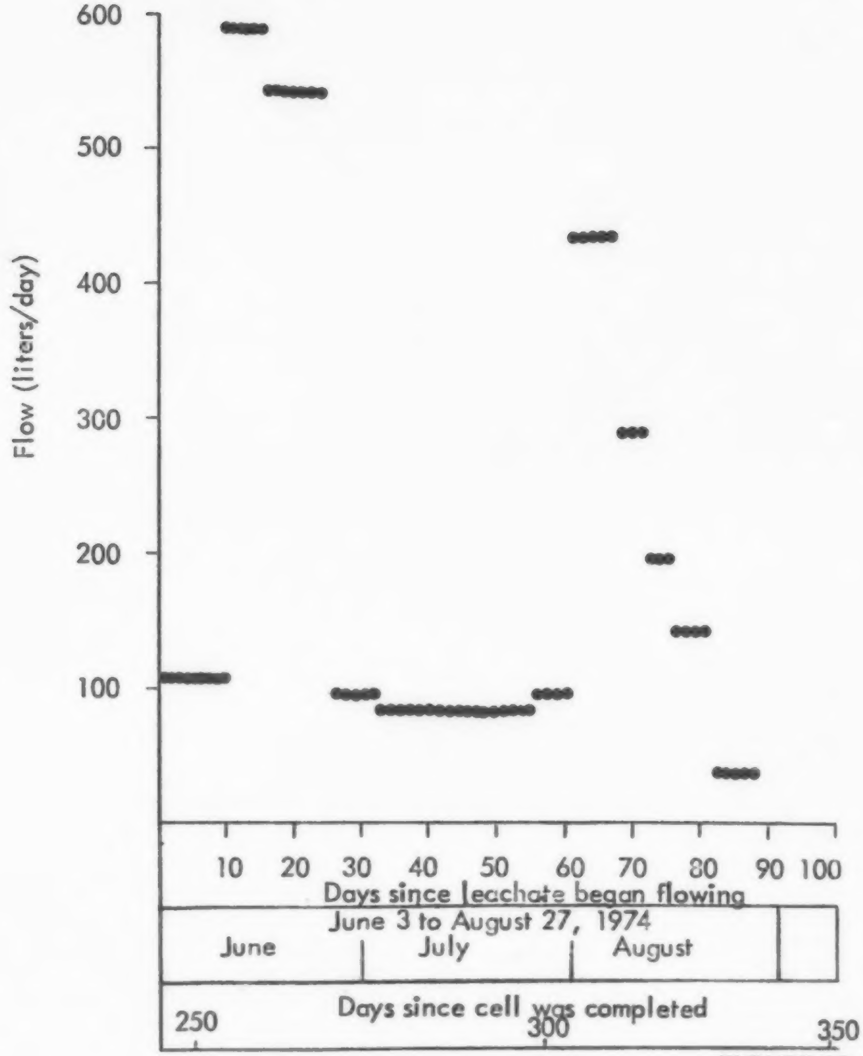


FIGURE 10-6

SUMP LEACHATE FLOWS

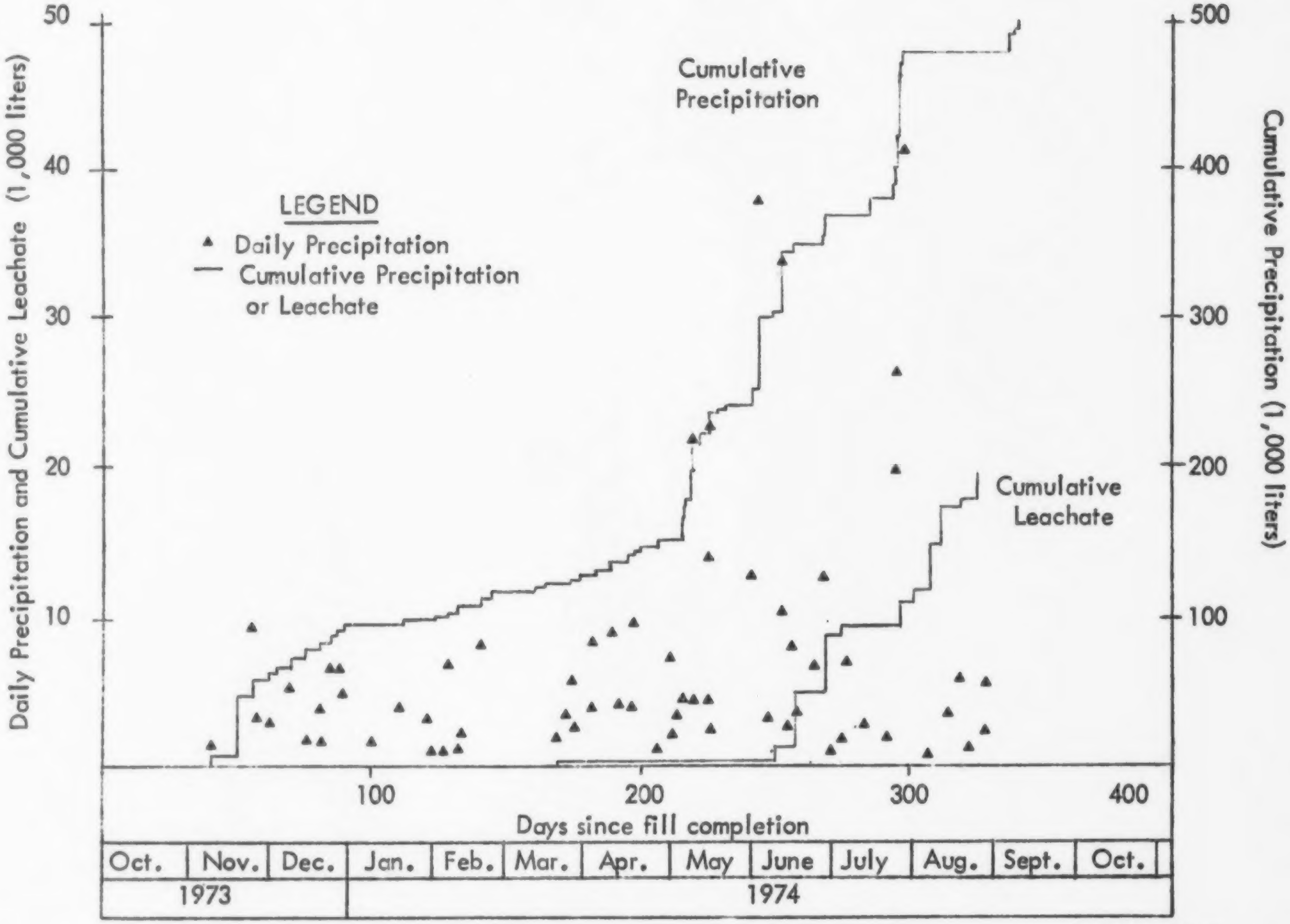


FIGURE 10-7
PRECIPITATION AND
SUMP LEACHATE TRENDS

(1) $I = O + Et + S$ where: I is inflow (precipitation)
O is outflow (leachate)
Et is evapotranspiration
S is storage (both in transit and as specific retention)

The total inflow during the period June 1,1974, to August 27, 1974, was 235,142 liters, and total outflow was 18,810 liters. Outflow was 8 percent of inflow (total precipitation for the period). Specific retention was assumed to be about 10 percent of the total pore space for the conditions in the cell and the geographical location. Specific retention, or field capacity, is the proportion of the total pore space in a soil or other material that will store water. This estimate was provided by the University of Minnesota Geology Department consultant, Dr. Pfannkuch.

The test cell contained the following distinct materials in layers:

Surface: glacial till, 0.3 m (1 ft) thick, pore space of 35 percent.

Bales: 3.35 m (11 ft) thick, pore space 6 percent.

Sand: Mixed, clean washed sand, 0.3 m (1 ft) thick, pore space 27 percent.

The pore space in the sand and till were obtained from geology data provided by Professor Pfannkuch. The empty space between bales (bale pore space) was calculated from bale spacing measurements taken at the balefill during monitoring, and neglects absorption into the bales. The total available storage space of 327,500 liters was calculated as: sand - 69,000 liters; bales - 169,000 liters; and till - 89,500 liters. Ten percent, or 32,750 liters were attributed to specific retention.

Values for evapotranspiration obtained from the Minnesota Geological Survey were 78 to 87 percent in the St. Paul region. A value of 87 percent was assumed for Et. At 87 percent for Et the volume of 32,750 calculated for available storage space was filled during the June 3, 1974 rainfall (see Table 10-3), as shown in the following calculation using equation (1):

$$\text{precipitation (Nov. 1, 1973 - June 3, 1974)} - 0.87 \times \text{precipitation} = S_{sr} + O$$
$$= 253{,}461 - 0.87(253{,}461) = 32{,}950 \text{ liters.}$$

During the summer 1974 months, the rate of sump leachate outflow closely paralleled the precipitation inflow. Precipitation not accounted for by outflow during June 1 to August 27, 1974, may be assumed to have been absorbed into the solid waste bales or lost to evapotranspiration and runoff. Precipitation occurring from October 1973 through May 31, 1974 filled the storage space in the till, bales and sand, and was lost to evapotranspiration; hence no leachate was observed during this period.

b. Sump Leachate Characteristics. The chemical constituents in the test cell sump leachate are given in Table 10-4. The analyses of the weekly and monthly leachate samples from the test cell are given in Figures 10-8 through 10-12.

TABLE 10-4
ST. PAUL BALE TEST CELL SUMP LEACHATE ANALYSIS

Date, 1974 (Days Since Filled)	pH	Coliform, MPN/100ml		Constituents, mg/l					Nitrogen Series, N mg/l		
		Total	Fecal	BOD_5	Cl^-	$SO_4^=$	$S^=$	TDS	NO_3	NH_3	Organic
3/29 (182)	6.7	16,000	2,200	Insufficient sample volume (25 ml)				2,640[a]	0.34	--[b]	--
4/13 (197)	6.5	<3	<3	167	Insufficient sample			1,380[a]	0.97	--	--
4/28 (212)		240	78	Insufficient sample volume (25 ml)					--	--	--
5/21 (235)	6.8	≥2,400	210	25	411	0	<0.1	1,988	0.37	8	12.5
5/27 (241)	6.4	≥2,400	.14	125	367	0.7	<0.1	1,884	0.26	13	11.3
6/2 (247)	6.6	≥2,400	<3	155	355	1.0	<0.1	1,850	.28	10	13.0
6/16 (261)	6.4	≥2,400	<3	310	411	0	<0.1	1,912	.29	9	20.0
6/26 (271)	7.2	≥2,400	240	505	422	0.5	<0.1	2,200	.38	17.4	14.6
7/2 (277)	7.1	≥2,400	43	145	444	0	<0.1	2,051	.35	24.4	16.2
7/30 (305)	7.0	9	<3	50	410	0	<0.1	1,900	.5	20.3	17.5
8/6 (312)	7.1	1,100	210	545	350	1.1	<0.1	2,462	.35	--	--
8/14 (320)	7.1	23	<3	140	395	0.8	<0.1	1,564	.28	25.0	20.0
9/3 (339)	6.3	43	15	225	447	1.0	<0.1	2,015	.30	26.2	16.5
9/17 (353)	6.5	≥2,400	120	0	385	0	<0.1	1,854	--	--	--

TABLE 10-4
ST. PAUL BALE TEST CELL SUMP LEACHATE ANALYSIS
(Cont.)

Date, 1974 (Days Since Filled)	pH	Coliform, MPN/100ml		Constituents, mg/l					Nitrogen Series, N mg/l		
		Total	Fecal	BOD_5	Cl^-	$SO_4^=$	$S^=$	TDS	NO_3	NH_3	Organic
9/25 (361)	6.8	2,400	150	25	405	1.0	0.1	1,960	--	--	--
10/14 (380)	6.8	2,400	93	85	390	0	0.1	1,956		--	--
10/21 (387)	6.4	2,400	75	85	350	0.5	0.1	2,008	--	--	--
10/28 (394)	6.9	2,400	64	80	418	0.7	0.1	1,888	--	--	--

[a] Specific conductivity, in μmhos/cm (insufficient sample to perform TDS analysis). TDS is approximately 0.85 times the specific conductivity.

[b] No data indicates insufficient quantity of sample to perform this analysis.

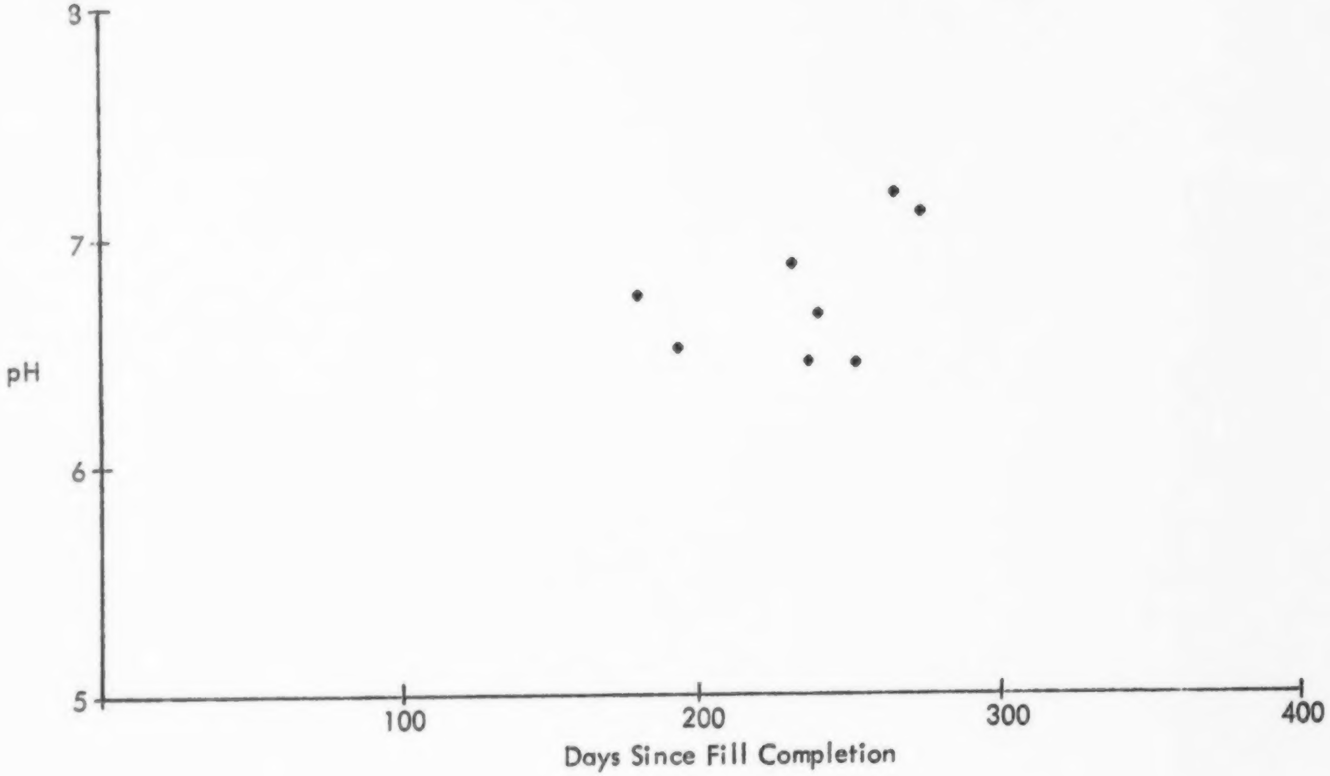


FIGURE 10-8
SUMP LEACHATE pH

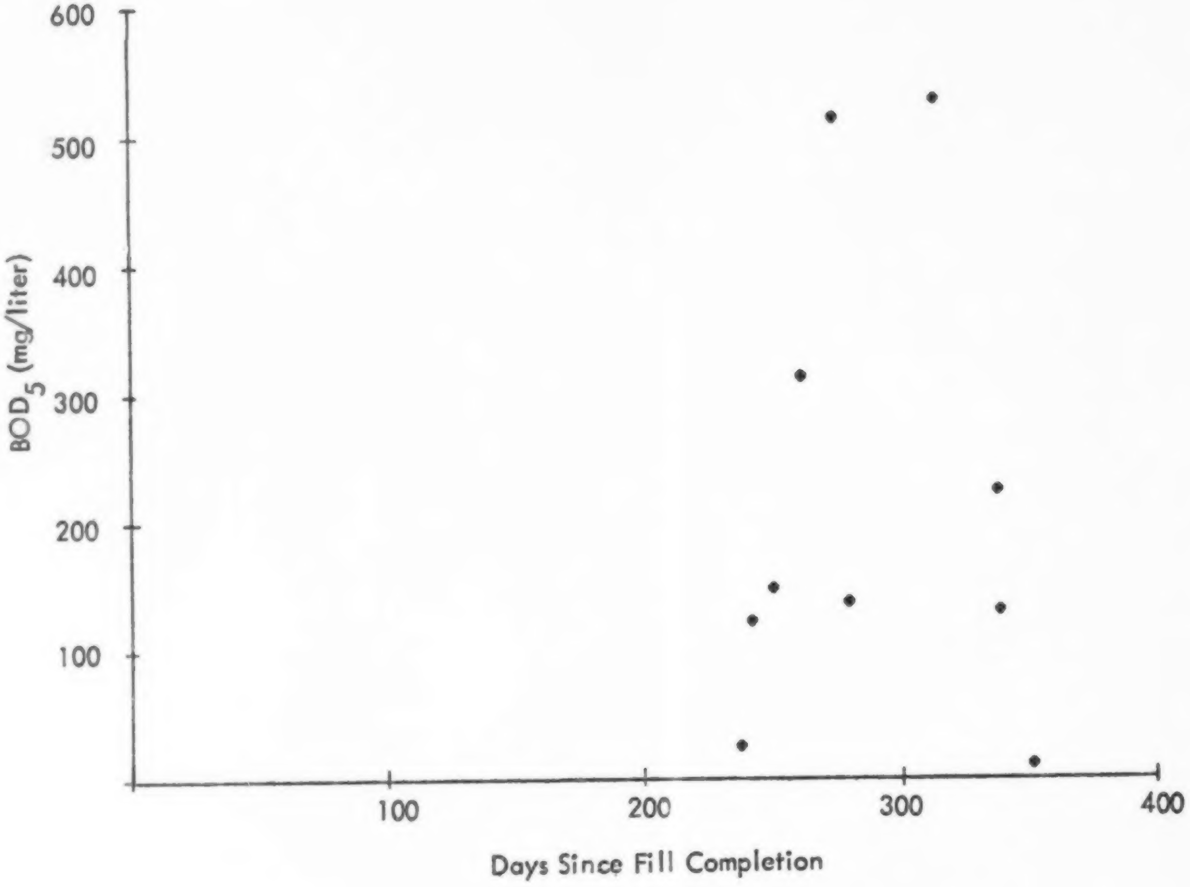


FIGURE 10-9
SUMP LEACHATE BOD$_5$

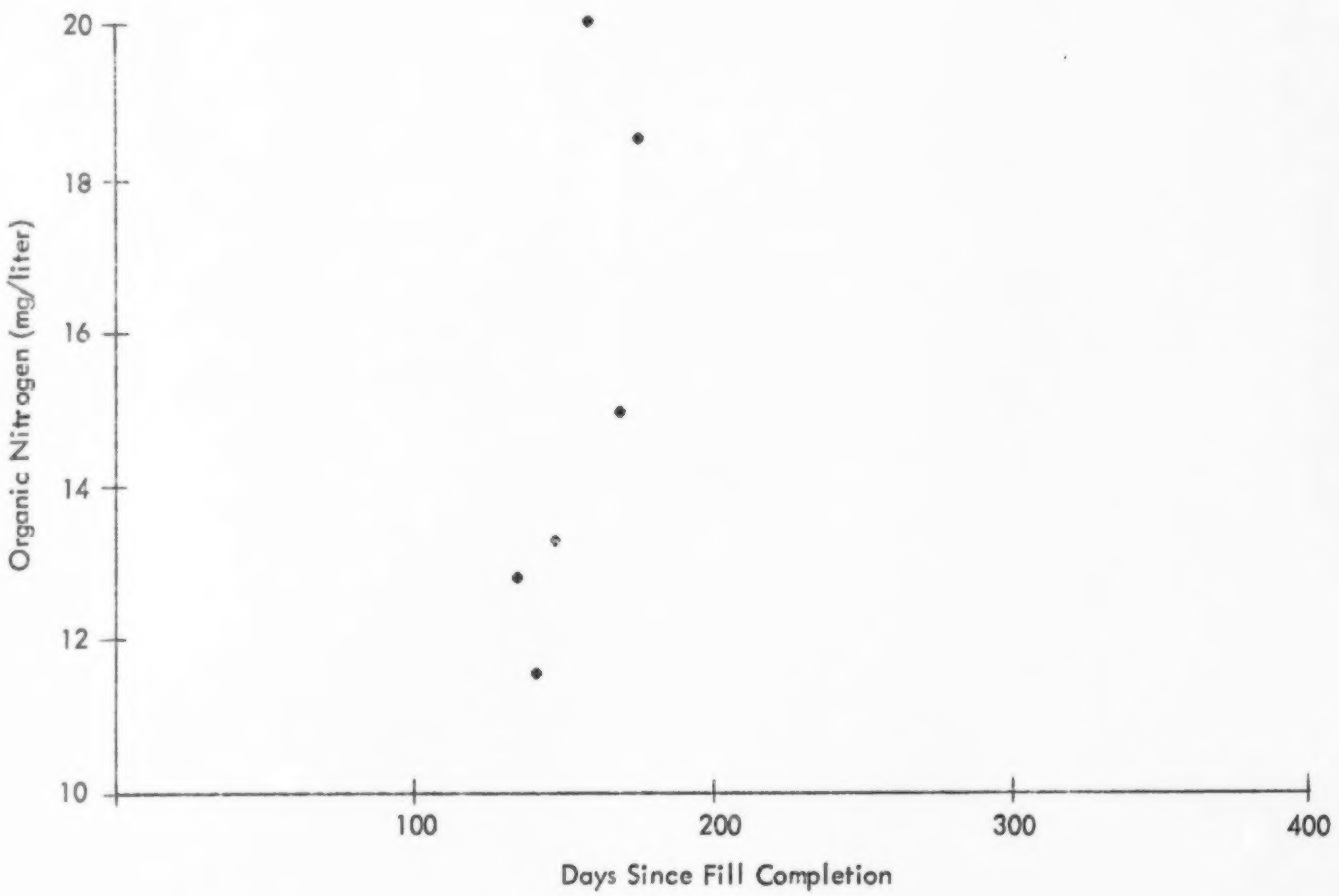


FIGURE 10-10
SUMP LEACHATE
ORGANIC NITROGEN

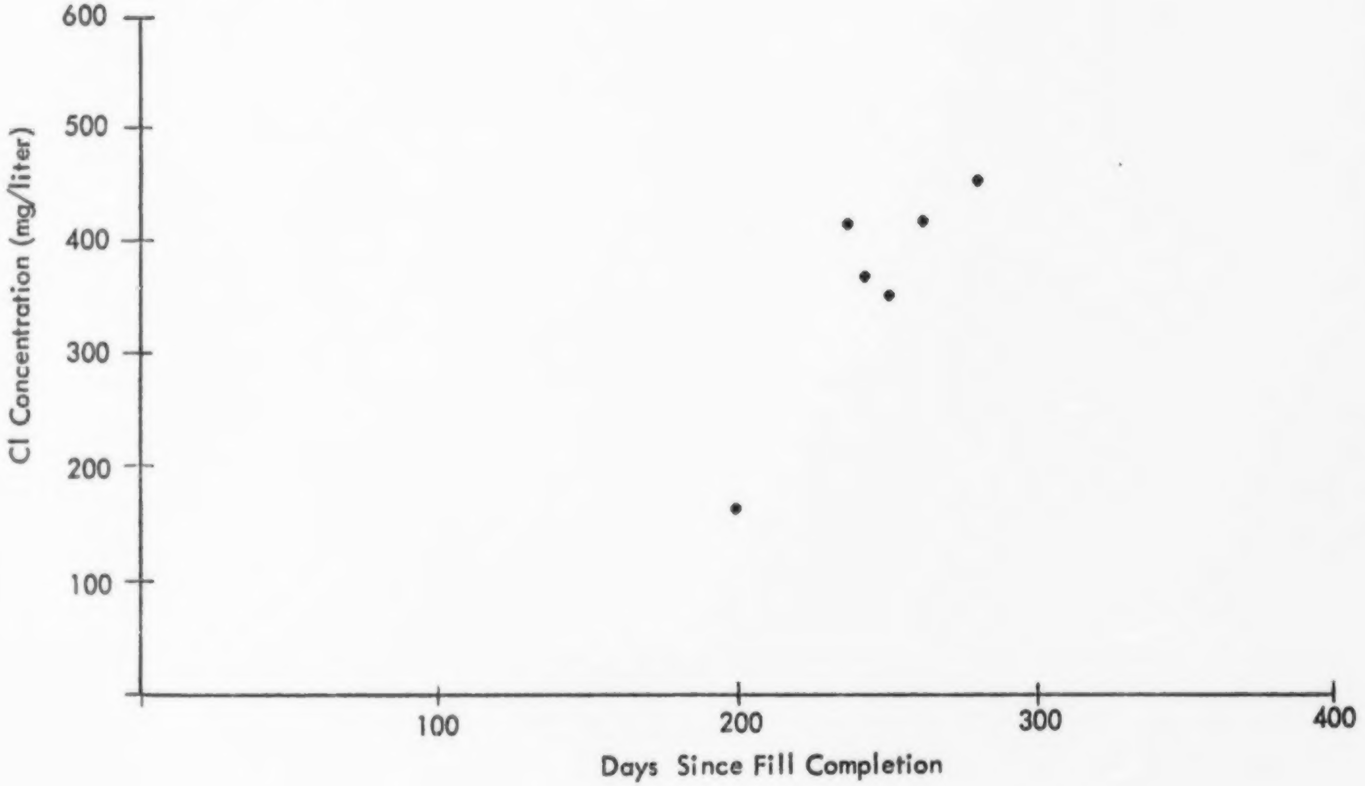


FIGURE 10-11
SUMP LEACHATE Cl

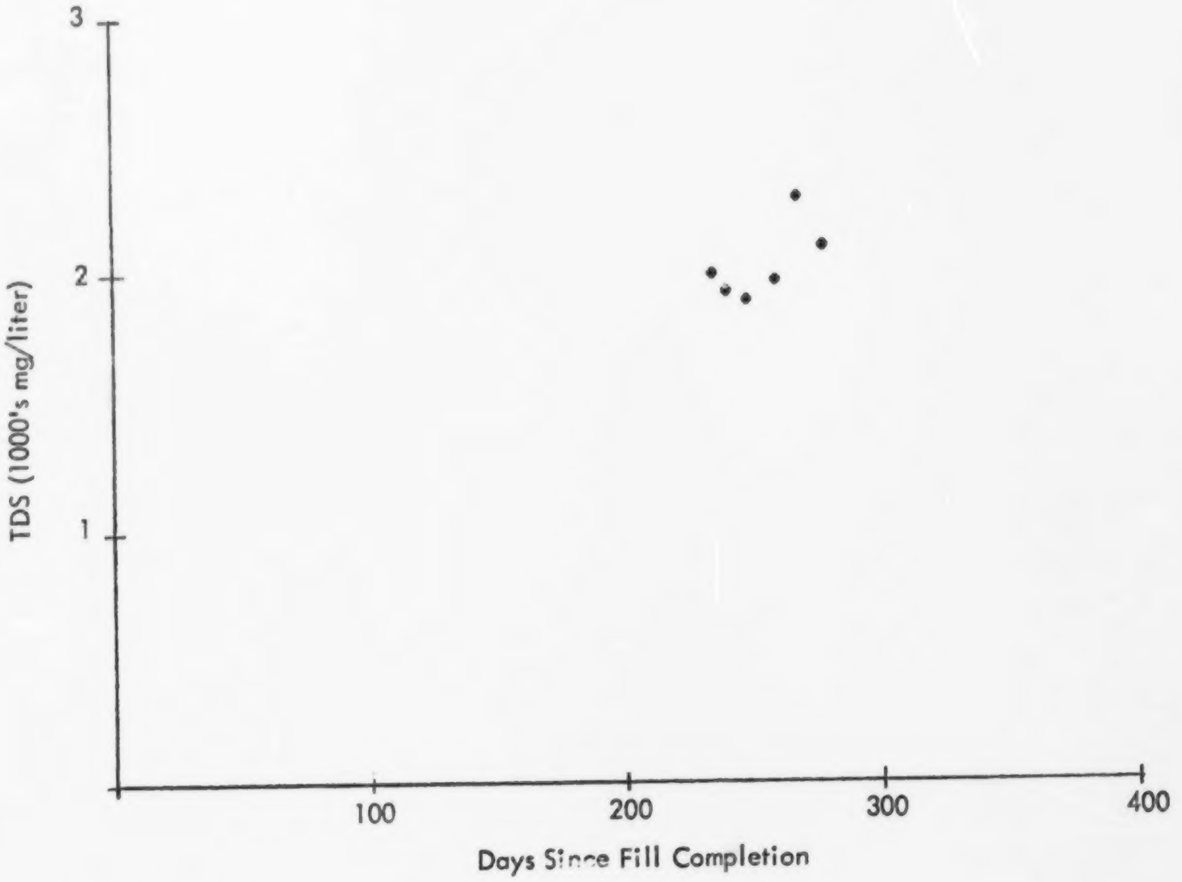


FIGURE 10-12
SUMP LEACHATE TDS

The data in Figure 10-8 indicate an average pH of 6.7 for all sump leachate samples which is approximately neutral. Figure 10-9 indicates an initial BOD_5 (5/21) of 25 mg/l. Subsequently, the BOD_5 level rose to a peak of 545 mg/l about 312 days after test cell completion.

The nearly neutral pH and low BOD_5 values indicate that the biodegradation rate was low and probably occurred only on the bale faces. Organic nitrogen levels fluctuated between about 10 and 20 mg/liter (Figure 10-10). Chlorides (Figure 10-11) and total dissolved solids show level trends (Figure 10-12).

The St. Paul bale test cell average leachate composition is compared on Table 10-5 with leachate from other types of solid waste landfills. As can be seen, the bale leachate is low in BOD_5, chlorides, and TDS, compared with values of other landfills.

c. Lysimeter Leachate. Leachate samples were also taken from the lysimeters located at various positions on the test cell. The measured chemical constituents of the test cell lysimeter leachate are given in Table 10-6. The trends of lysimeter leachate analyses are illustrated in Figures 10-13 through 10-17.

Figure 10-13 shows that as the depth increases, the BOD_5 also increases. The total dissolved solids (TDS) shown in Figure 10-14 is also a function of the depth of the cell: TDS increases with an increase in depth. Figure 10-15 shows only two depths represented for organic nitrogen. Quantities of leachate sample were insufficient for organic nitrogen determination in many cases. High values obtained in March are attributable to first analysis of the winter's nitrogen accumulations after the first thaw. However, from the data plotted, quantities of organic nitrogen appeared to increase with an increase in depth. Chlorides also increased with an increase in depth as seen in Figure 10-16. The pH (Figure 10-17) remained at an approximate average of 6.86 for all depths.

2. Temperature. Figures 10-18 through 10-21 display temperature trends from data collected at four different test cell stations. For each station, temperatures at three different levels were recorded. Figure 10-22 shows the station average temperatures at 0.6 , 1.5 , and 2.4 meter depths, and average ambient air temperatures. With the exception of an early sharp increase in bale temperatures, trends in the baled solid waste followed fluctuations in ambient air temperatures. The early increase in bale temperatures is a function of initial intense decomposition. Figure 10-23 compares change in temperatures over time at Oceanside and Spadra, in California, and at St. Paul. The comparisons are made to illustrate any similarities and differences between baled and unbaled waste. The Oceanside data on mixed sludge and solid waste is included because the potential exists for baling mixed sludge and solid waste (limited testing was conducted in St. Paul). All curves show at least a slight initial increase in temperature before decreasing to a levelling trend. Three differences between St. Paul and other temperature curves are: a higher initial peak temperature; a generally higher level trend (exceeded only by Spadra Cell B at 3 meters); and more extreme variation during the "level trend" part of the curve. The higher initial peak temperature and

TABLE 10-5
LEACHATE COMPONENT COMPARISONS OF DIFFERENT LANDFILLS

Landfill Sites	Chemical Constituent										
	pH	Coliform (MPN/100ml) Total	Coliform (MPN/100ml) Fecal	BOD_5 mg/l	Cl^- mg/l	Sulfides mg/l	TDS mg/l	NO_3^- mg/l	NH_3 mg/l	Organic N mg/l	$SO_4^=$ mg/l
Dupage Landfill[1]											
MM61	--[a]	--	--	125	205	--	1,104	0.14	--	—	1
MM63	--	--	--	4,560	946	--	5,910	0.5	--	--	1
Blackwell Landfill[1]	--	--	--	54,610[b]	1,697	--	19,144	1.7	--	--	680
Madison Landfill[2]	5.8	--	--	1,550	--	--	--	--	--	--	--
Shredded Refuse	8.1			9,900						--	
Wisconsin Landfill[2]	7.0	--	--	--	98- 2,800		--	--	--	--	--
Winnetka Landfill[1]											
LW17	--	--	--	6,400	429	--	2,306	0.50	--	--	13.6
LW13	--	--	--	105	70	--	584	0.20	--	--	5
LW53	--	--	--	250	701	--	994	0.43	--	--	1
St. Paul Baled Landfill (averages of all data) Lysim.											
Depth 0.8 m	6.9	6	2	90	47	0	884	0.05	0.6	19	36.3
Depth 1.4 m	6.9	9	3	352	259	0.02	1,670	0.17	13.05	16.4	15.5
Sump	6.7	2615	310	185	379	0	1,982	0.4	15.4	14.8	1.6
Range of Values	5.8- 8.1	6- 2615	2- 310	90- 9,900	47- 2,800	0-0.02	584- 19,144	0.05- 1.7	0.6- 15.4	14.8- 19	1- 680

TABLE 10-5 (Cont.)

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[a] Indicates no analysis data.
[b] 20-day BOD value.

Sources:

1. Hydrogeology of Solid Waste Disposal Sites in Northeastern Illinois. G. M. Hughes, R. A. Landon & R. M. Farvolden. Illinois State Geological Survey. U. S. Environmental Protection Agency, 1971.

2. Treatability of Leachate from Sanitary Landfills. W. C. Boyle and R. K. Ham, Department of Civil and Environmental Engineering, University of Wisconsin, Madison, Wisconsin.

TABLE 10-6
ST. PAUL BALE TEST CELL LYSIMETER LEACHATE ANALYSIS

Date 1974	Days Since Fill.	Lys. Depth m	(ft)	pH	Coliform, MPN/100 ml		Constituents, mg/l					Nitrogen Series, N mg/L		
					Total	Fecal	BOD_5	Cl^-	$SO_4^=$	Sulfides	TDS	NO_3	NH_3	Organic
3/21	174	0.9	(3)	6.6	<3	<3	220	261.1	337	0.23	3178	0.14	--[a]	80
		1.5	(5)	--	<3	<3	485	--	--	--	--	0.34	--	--
		2.3	(7.5)	6.5	<3	<3	--	--	109	--	--	0.21	--	225
		3.4	(11)	7.0	<3	<3	180	205.5	--	0.23	--	0.19	--	--
3/29	182	0.9	(3)	6.3	<20	<20	520	200	18	0.17	2228	0.14	--	65
		1.5	(5)	7.0	<20	<20	305	300	35	0.26	2100	0.58	--	40
		2.3	(7.5)	6.7	<20	<20	340	211	0	--	--	0	--	--
4/22	206	0.3	(1)	6.8	<3	<3	--	--	--	--	--	0.18	0.075	--
		0.8	(2.5)	7.0	<3	<3	20	11.1	22	0.04	650	0.11	0.065	0
		1.2	(4)	7.0	<3	<3	235	255.5	--	--	--	0.18	--	--
4/28	212	0.8	(2.5)	7.1	<3	<3	10	0	27	0.04	694	0.11	0.1	--
		1.5	(5)	7.0	<3	<3	--	233	--	0.26	--	0.16	--	--
5/21	235	0.8	(2.5)	7.3	9	<3	70	33.3	2.4	<.1	638	0.04	--	--
		1.4	(4.5)	7.0	<3	<3	300	211	13.9	<.1	1,608	0.13	--	--
5/27	241	0.8	(2.5)	6.9	4	<3	45	22.2	2.8	<.1	748	0	--	--
		1.5	(5)	6.6	23	4	180	300	11.0	<.1	2,098	0.02	--	--
6/2	247	0.8	(2.5)	7.15	20	<3	45	16.7	3.6	<.1	702	0.025	2	6.3
		1.4	(4.5)	7.0	<3	<3	295	--	--	<.1	--	0.095	--	--

TABLE 10-6 (Cont.)
ST. PAUL BALE TEST CELL LYSIMETER LEACHATE ANALYSIS

Date 1974	Days Since Fill.	Lys. Depth m (ft)	pH	Coliform, MPN/100 ml		Constituents, mg/l					Nitrogen Series, N mg/l		
				Total	Fecal	BOD_5	Cl^-	$SO_4^=$	Sulfides	TDS	NO_3	NH_3	Organic
6/16	261	0.8 (2.5)	7.05	<3	<3	35	12.2	1.9	<.1	651	0.07	1.5	4.4
		1.5 (5)	7.2	4	<3	455	--	--	<.1	--	0.13	--	--
6/26	271	0.8 (2.5)	6.7	4	<3	10	22	27	<.1	651	0.07	1.1	3.3
7/2	277	0.8 (2.5)	6.6	9	<3	25	22	28	<.1	726	0	0	4.5
		1.5 (5)	6.9	23	<3	485	211	15	<.1	1,900	0.14	10.0	10.2
7/8	283	0.8 (2.5)	6.8	7	<3	50	11	24	<.1	650	0.02	0	3.8
		1.4 (4.5)	6.9	28	<3	535	167	17	<.1	1,858	0.24	12.9	8.7
8/6	312	0.8 (2.5)	7.1	<3	<3	85	25	28	<.1	640	--	--	3.7
		1.4 (4.5)	--	<3	<3	510	--	--	<.1	--	--	--	--
8/14	320	0.8 (2.5)	7.1	<3	<3	100	20	--	<.1	--	--	--	--
8/21	327	1.4 (4.5)	6.8	<3	<3	250	300	11	<.1	1,805	0.12	16.5	10.2
8/27	333	0.8 (2.5)	7.0	<3	<3	90	33	17	<.1	595	0.02	--	--
		1.4 (4.5)	6.8	<3	<3	345	190	12	<.1	1,620	0.10	12.8	13.0
9/3	340	1.4 (4.5)	7.6	9	<3	340	205	--	<.1	--	0.18	--	--

[a] No data indicates insufficient quantity of sample to complete this analysis.

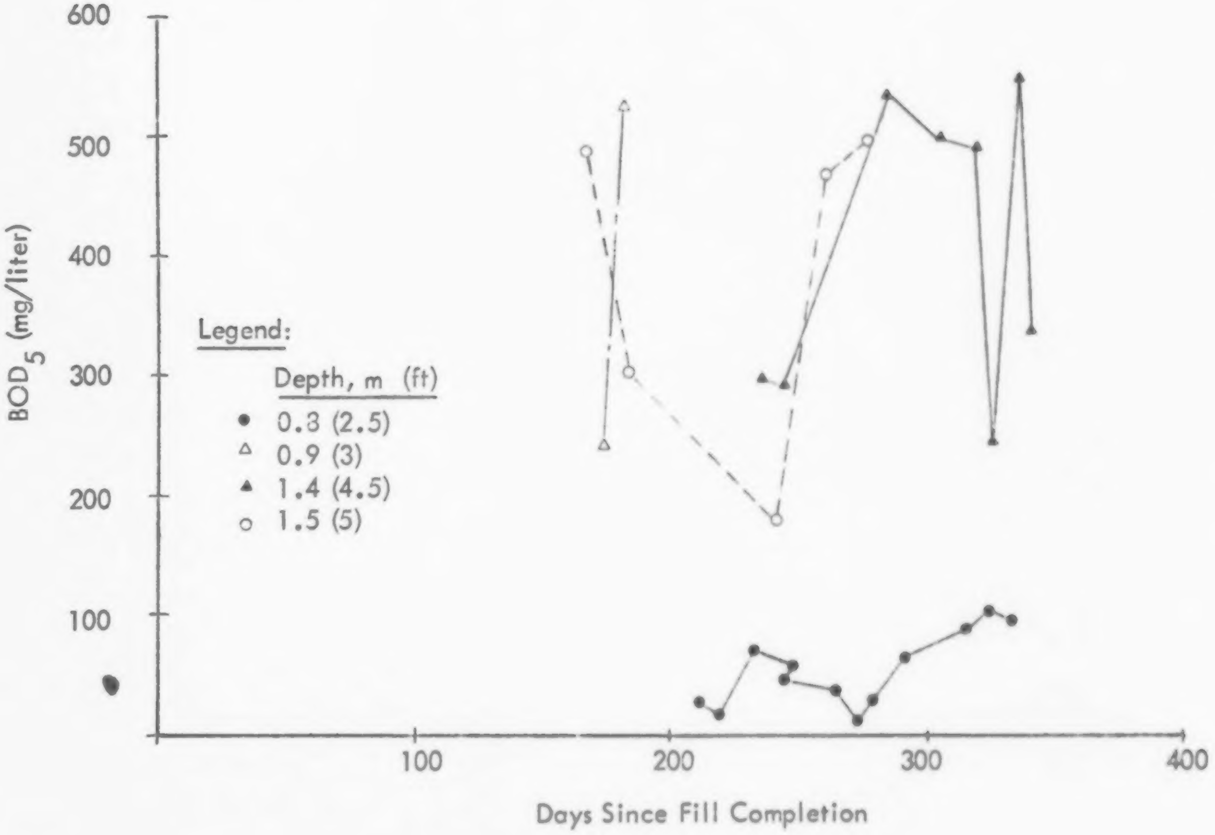


FIGURE 10-13
LYSIMETER LEACHATE
BOD$_5$

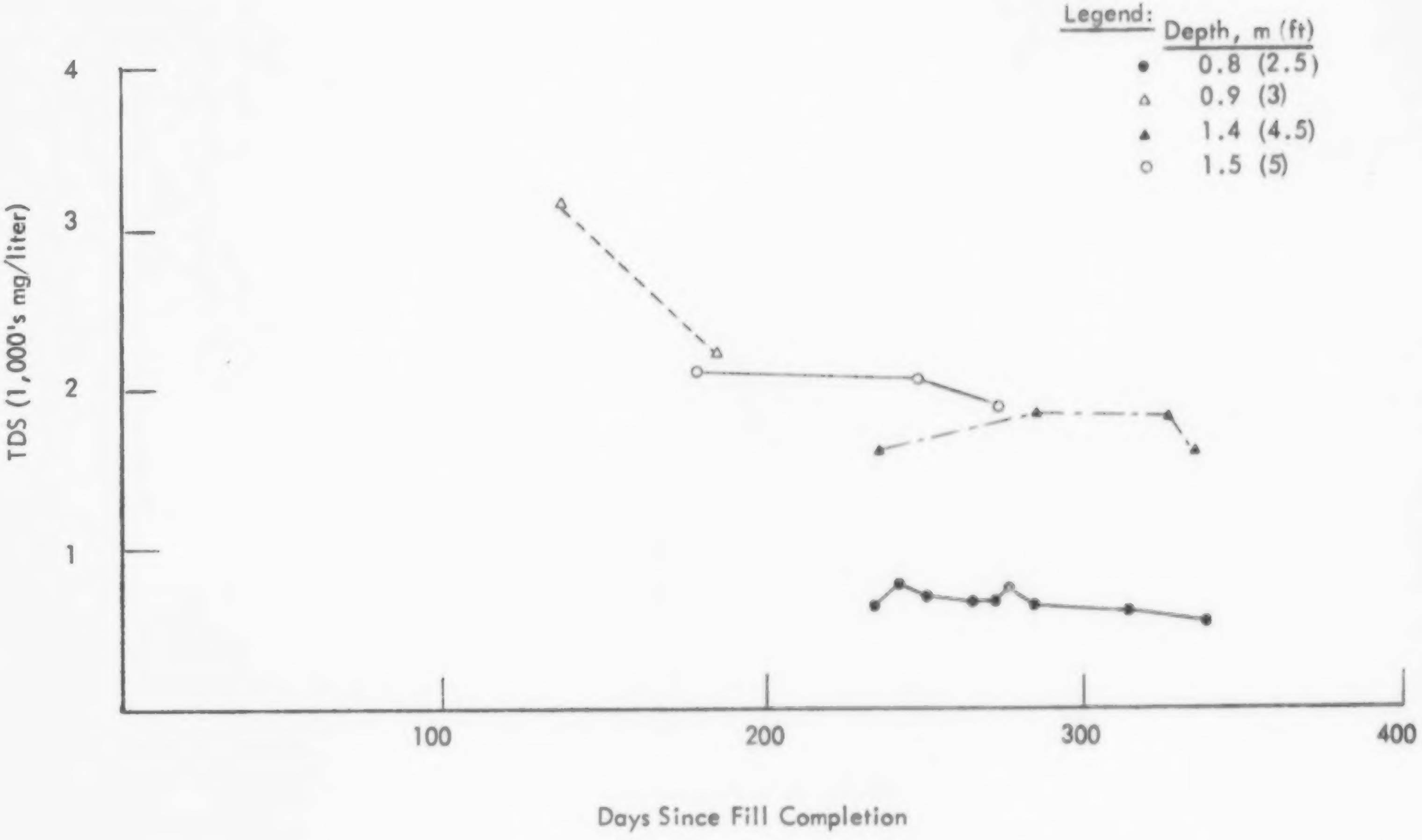


FIGURE 10-14
LYSIMETER LEACHATE TDS

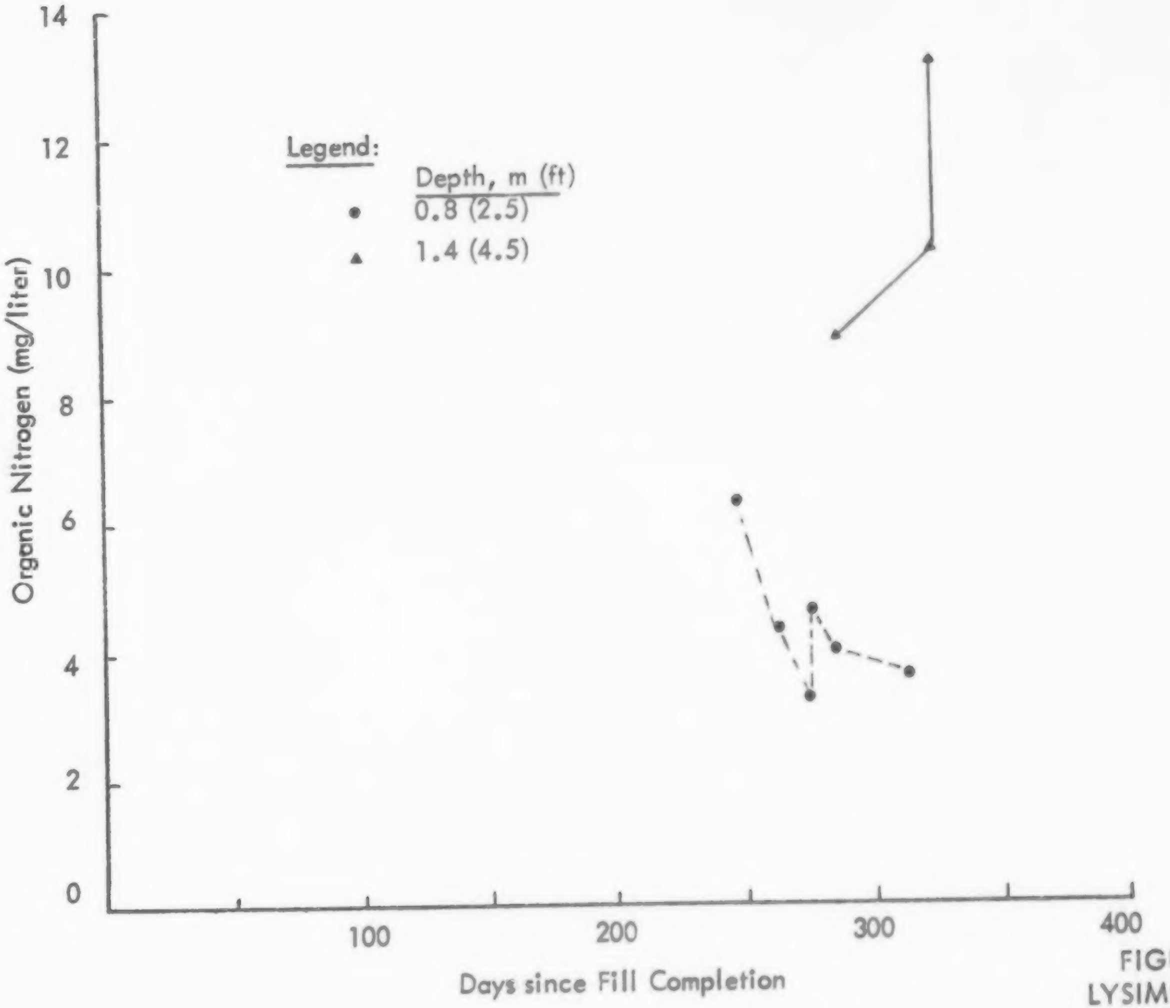


FIGURE 10-15
LYSIMETER LEACHATE
ORGANIC NITROGEN

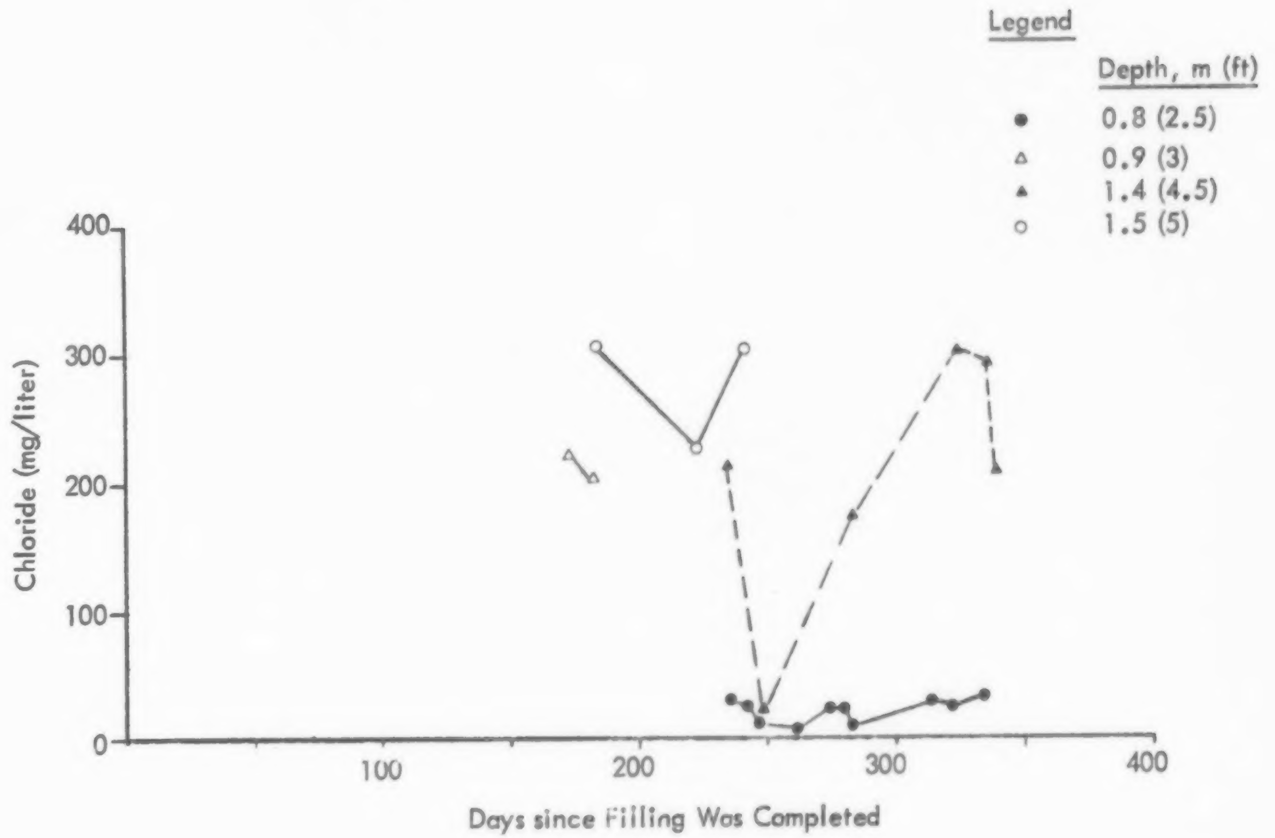


FIGURE 10-16
LYSIMETER LEACHATE:
Cl

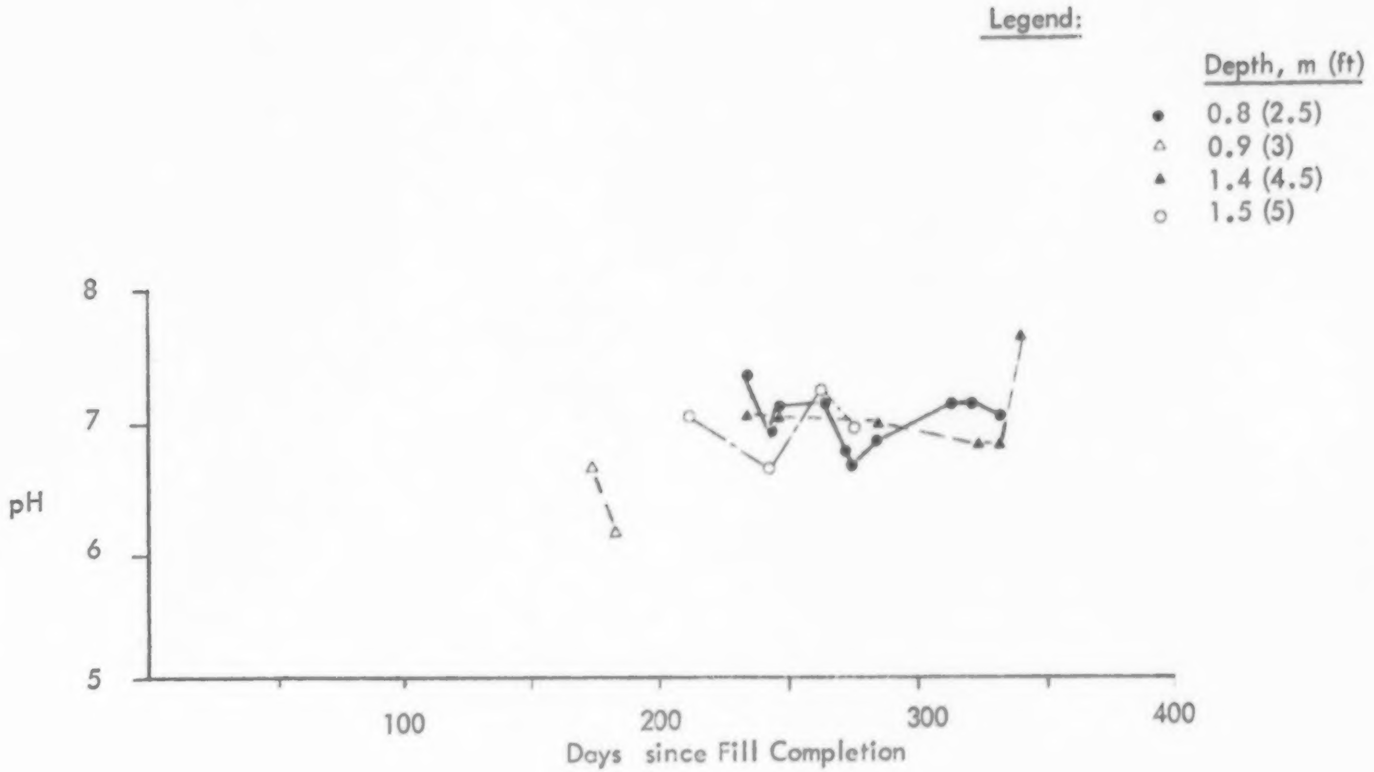


FIGURE 10-17
LYSIMETER LEACHATE
pH

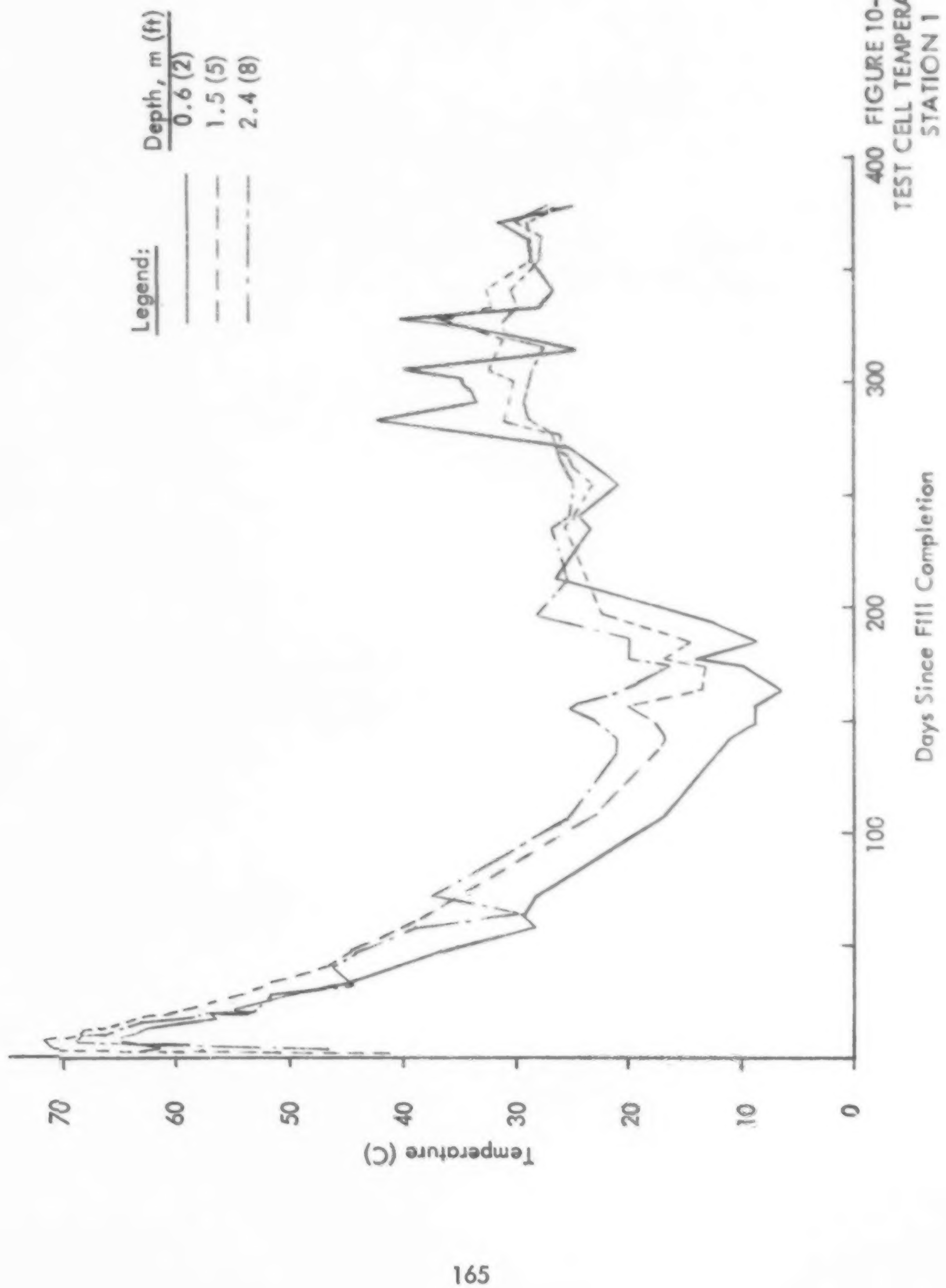


FIGURE 10-18
TEST CELL TEMPERATURE:
STATION 1

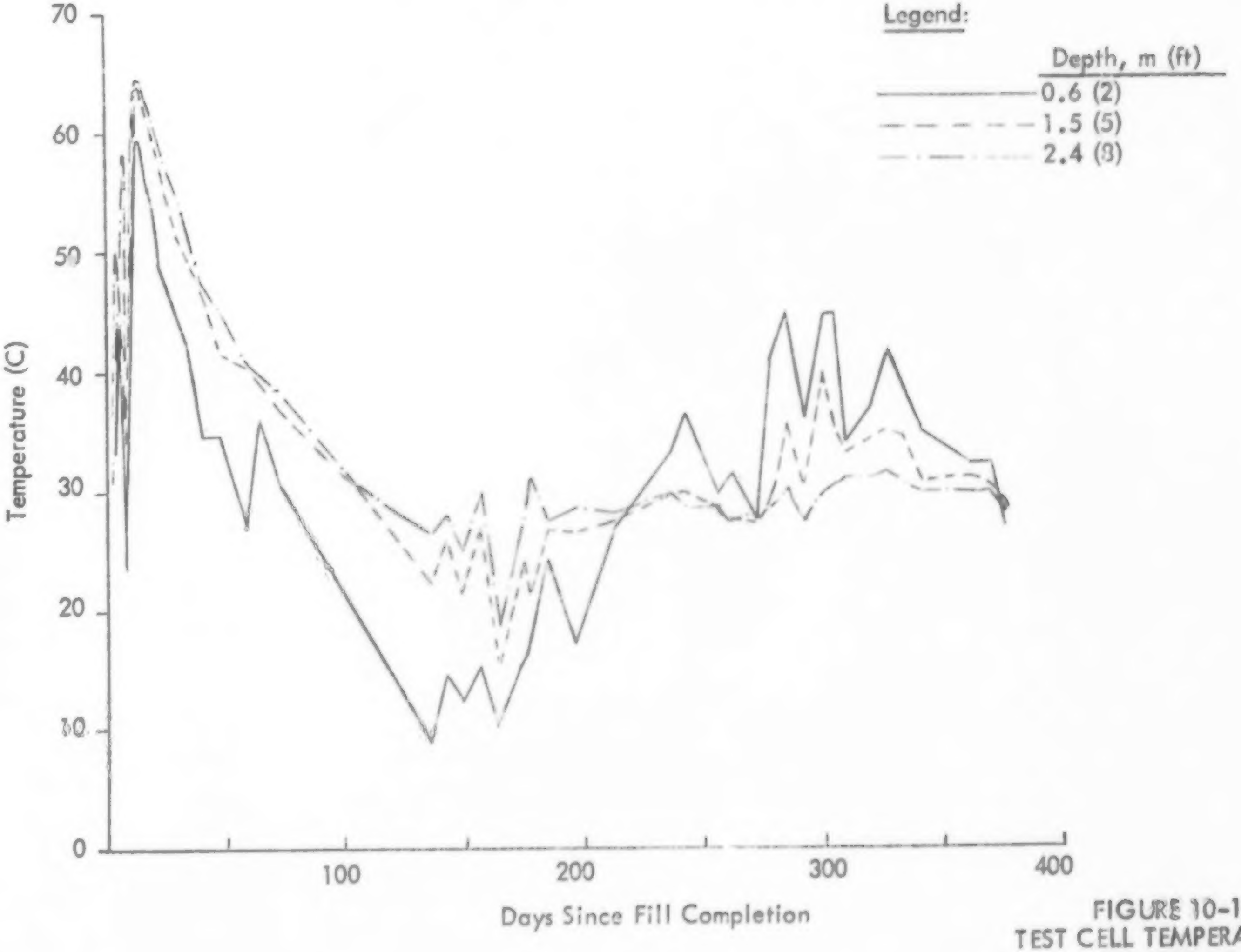


FIGURE 10-19
TEST CELL TEMPERATURE:
STATION 2

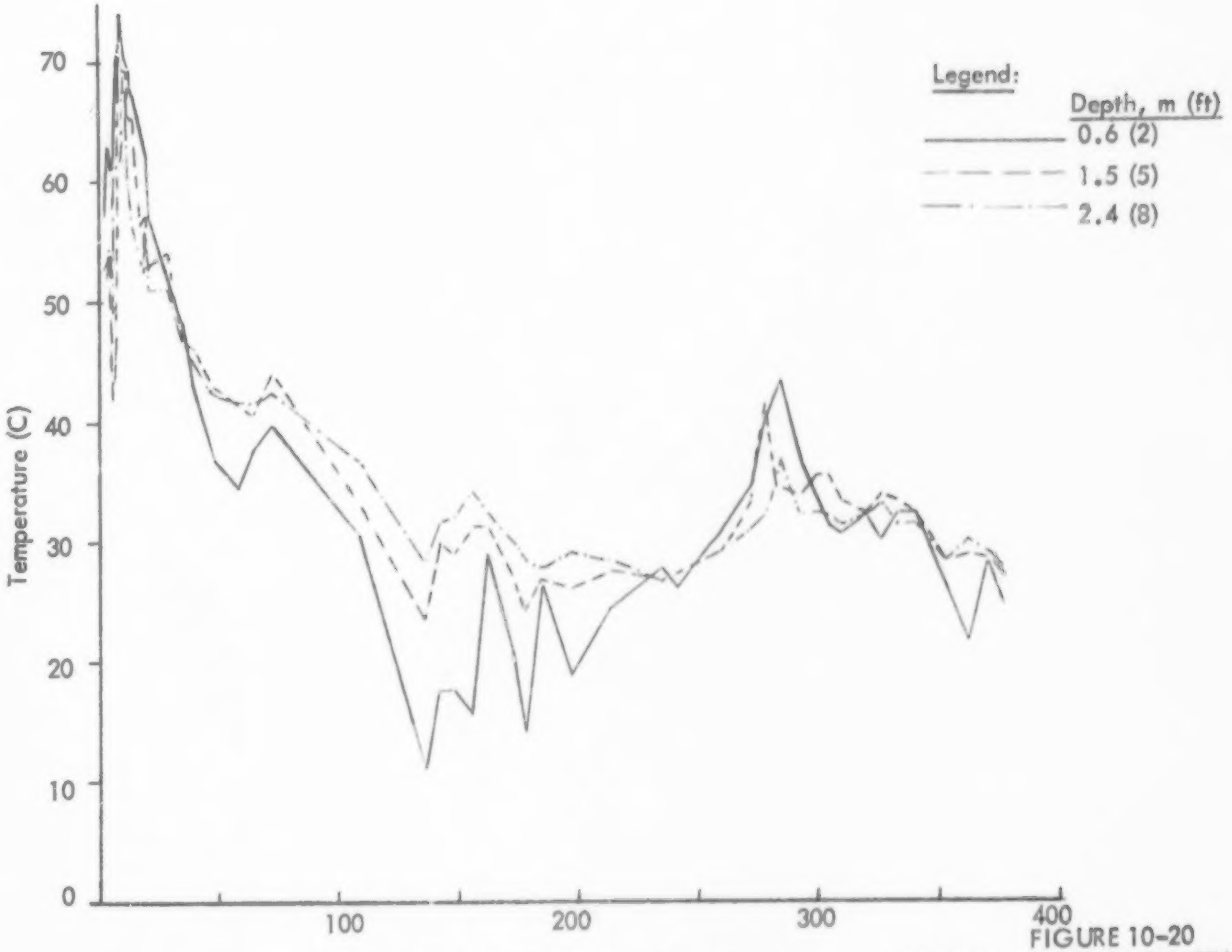


FIGURE 10-20
TEST CELL TEMPERATURE: STATION 3

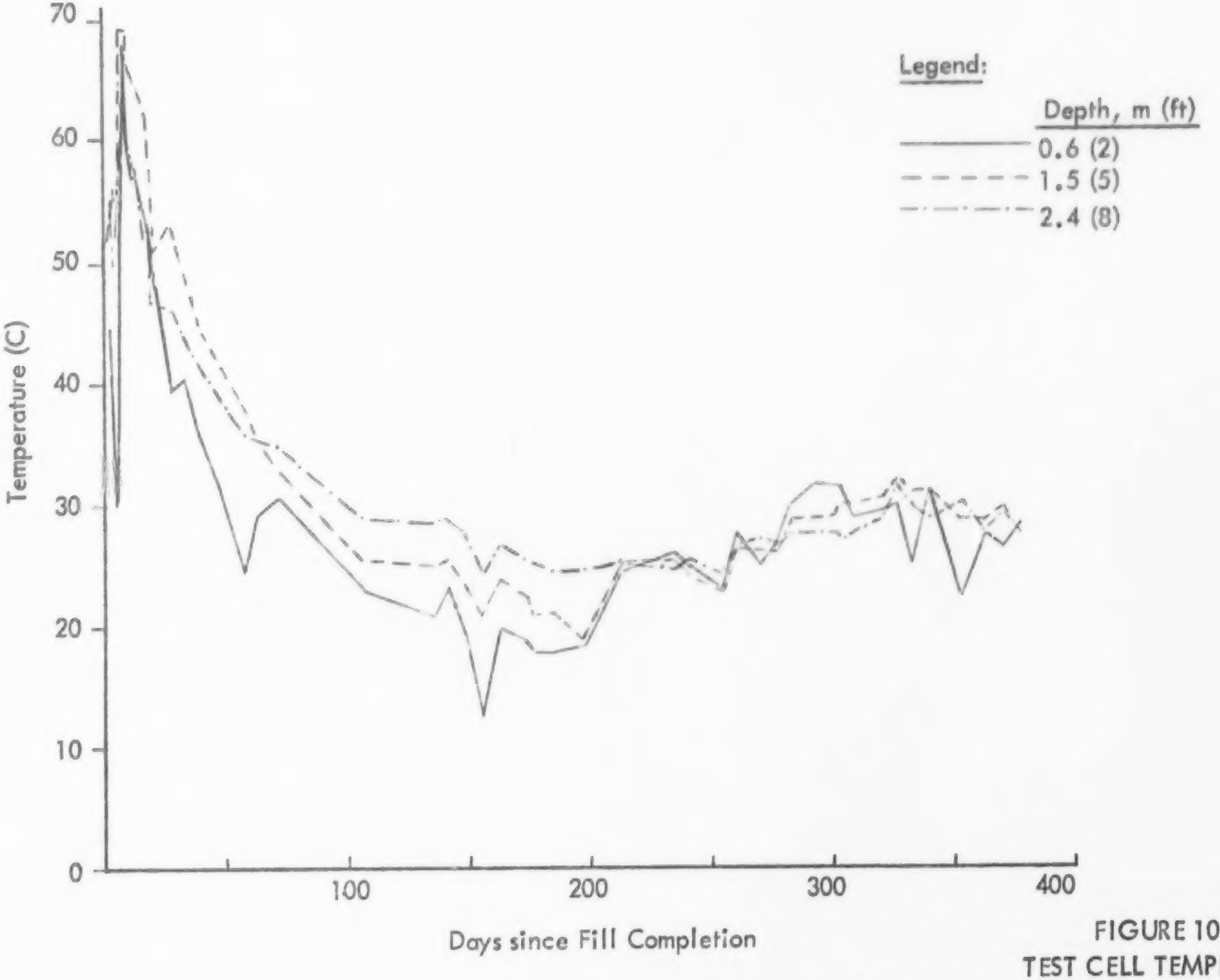


FIGURE 10-21
TEST CELL TEMPERATURE:
STATION 4

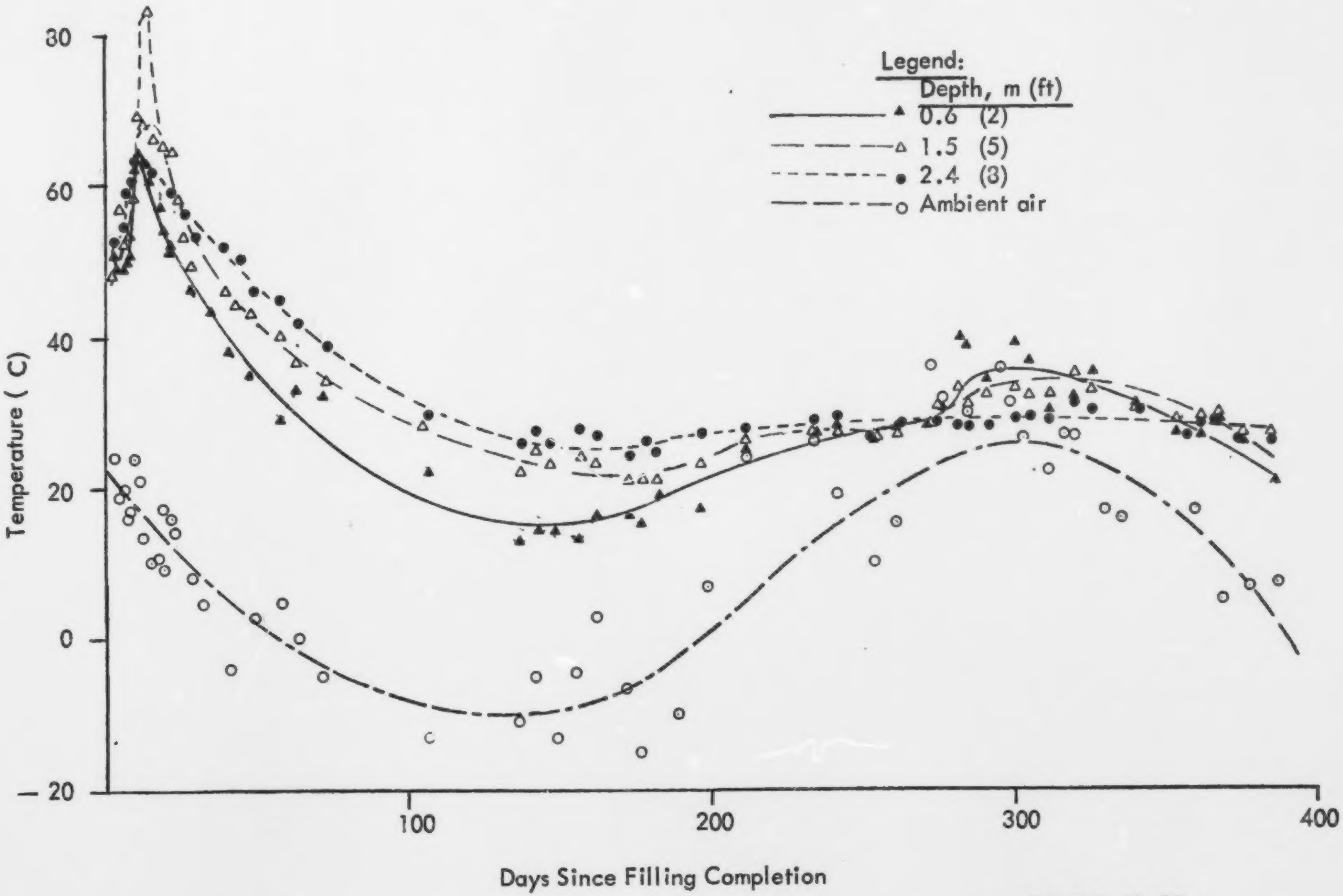


FIGURE 10-22
AVERAGE BALE AND AMBIENT
AIR TEMPERATURES

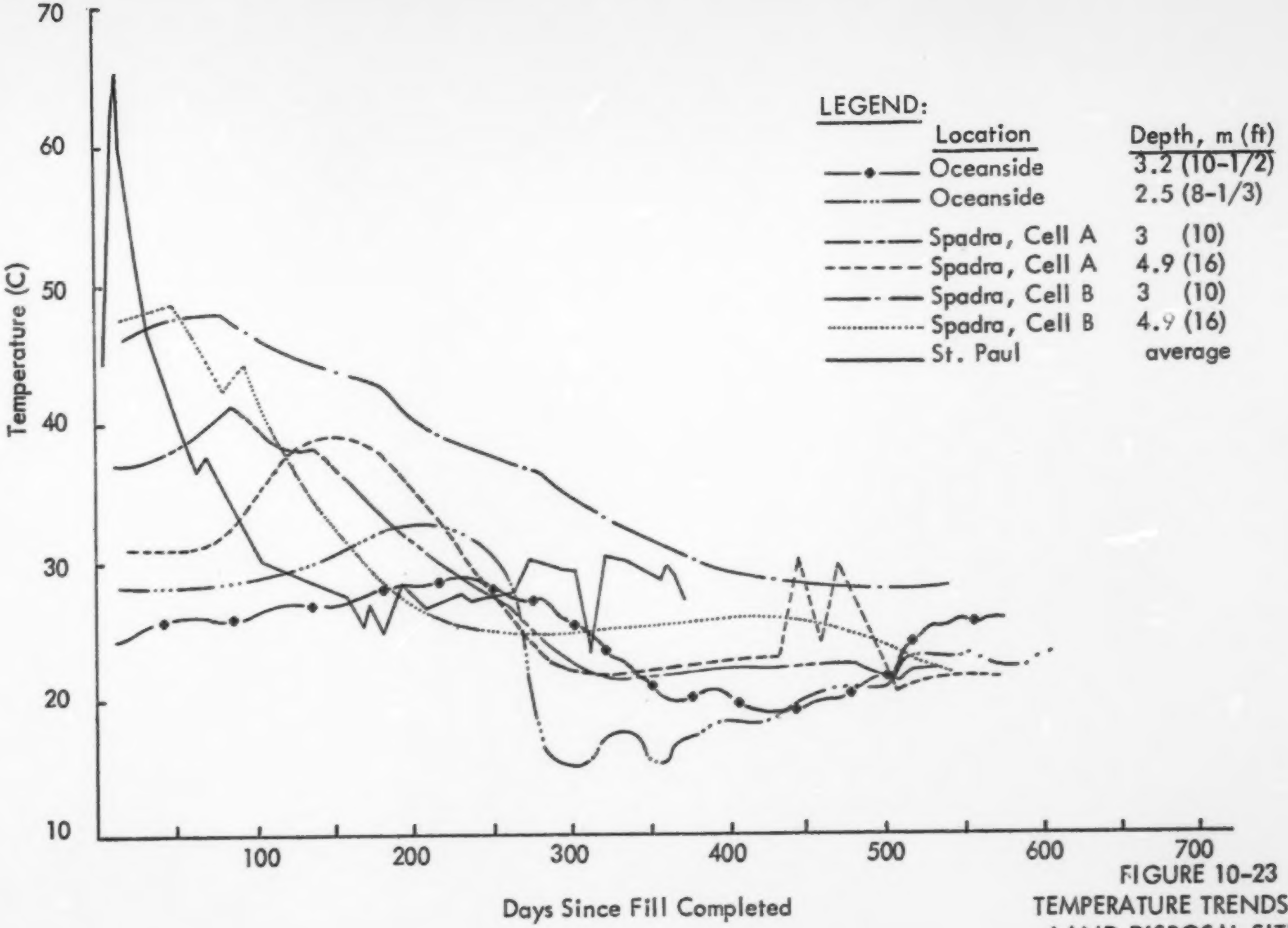


FIGURE 10-23
TEMPERATURE TRENDS AT
LAND DISPOSAL SITES

higher long-term trend temperature level may be a result of the high bale density, which will tend to retain more heat per unit volume and have fewer entrapped air void spaces that are not producing heat.

3. Gas Analysis. Figures 10-24 through 10-31 illustrate gas analyses trends at 0.9 and 2.4 meter depths for each monitoring station. Nitrogen percentages are omitted since gaseous nitrogen does not play a part in decomposition. Carbon dioxide and methane levels increased with time, while oxygen remained constant. These effects were more pronounced at the 2.4 meter depth, possibly due to less entrapment of outside air. In all cases, hydrogen sulfide levels remained lower than 0.1 percent. Sudden, infrequent drops in CO_2 concentrations and rises in O_2 probably represent air entry into sample bottles during sampling or shipping, and not actual decreased CO_2 gas generation in the balefill.

Figure 10-32 shows differences between St. Paul balefill generation of CO_2 and CH_4 and Los Angeles (conventional) and Oceanside (with sludge) landfill gas composition.

4. Expansion/Settlement. Elevation changes were determined at monitoring stations 1 to 5 by calculating the changes in distance between the elevation of the settlement riser attached to the plate under the bottom bales, and the elevations of the risers attached to plates and the concrete benchmark on top of the bottom, middle, and top bales. The differential elevation measurement method is shown in Figure 10-33.

The results of the elevation measurements averaged over the five stations at each level are plotted in Figure 10-34. Figure 10-35 compares data from St. Paul with data from a normal landfill at Spadra and a mixed sludge/solid waste landfill at Oceanside, both in California. The major points are that the test cell bales expanded during the first 10 days and remained basically stable over the following 12 months. As would be expected, the bottom bale expanded the least, due to the compressive weight of two upper bales and six inches of cover soil. The bales appear to provide a stable foundation which would allow immediate use of the land for light structures. However, since the duration of the monitoring was only for one year, long-term settlement trends are not yet known.

5. Core Sampling. The results of a one-time auger sampling are summarized in this section with regard to temperature, moisture content, organic content, and decomposition. One borehole in the new landfill was analyzed (180 days old); two boreholes in the test cell were analyzed (415 days old); and two boreholes in the old landfill were analyzed (about 730 days old).

a. Temperature. Temperature profiles by depth are given in Table 10-7. The average temperature decreases with the age of the fill material. This follows the normal decreasing temperature with age curve in landfills.

Temperatures in all bore holes increased with depth. This is due to the lessened effect of ambient temperature, and a corresponding higher biodegradation rate. The temperature increase with depth was greatest in the newest fill material, and least in the oldest

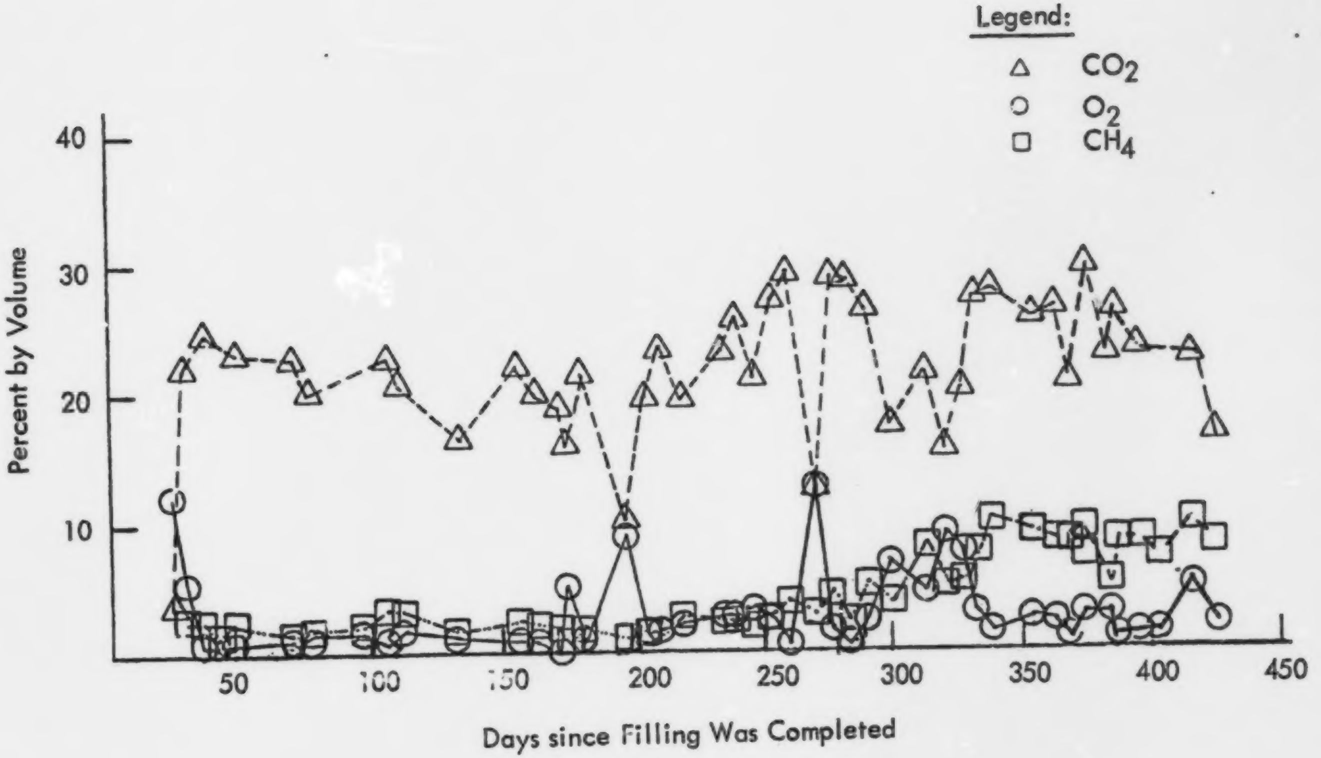


FIGURE 10-24
GAS ANALYSIS:
STATION 1 AT 0.9 M
(3 FT) DEPTH

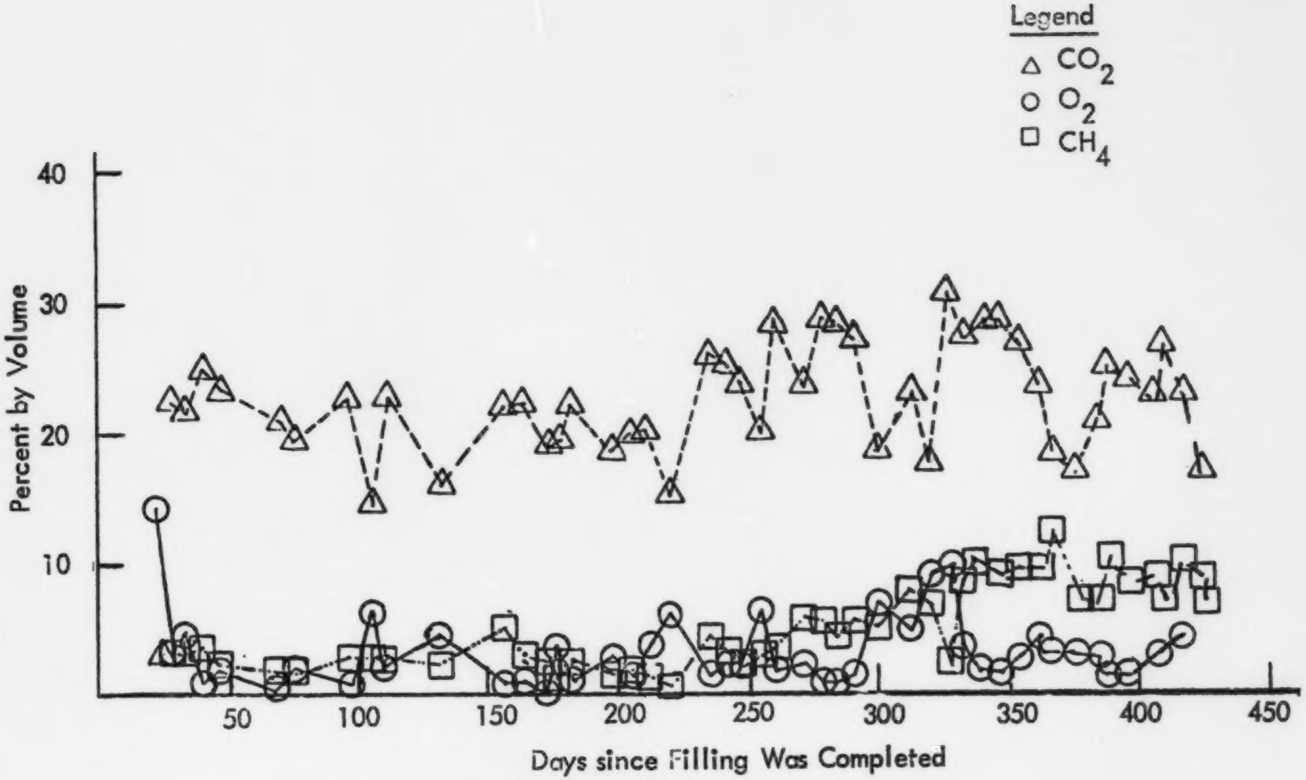


FIGURE 10-25
GAS ANALYSIS:
STATION 1 AT 2.4 M
(8 FT) DEPTH

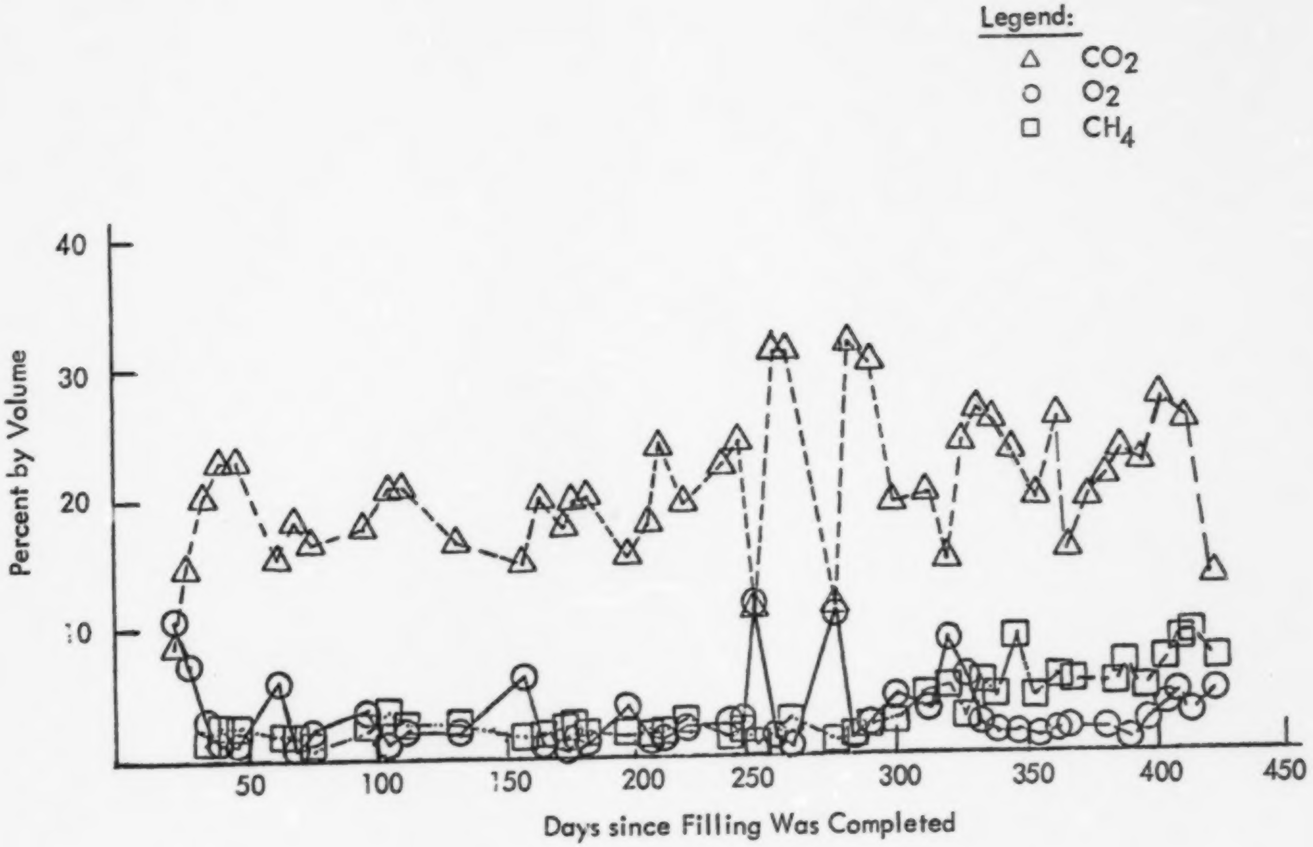


FIGURE 10-26
GAS ANALYSIS:
STATION 2 AT 0.9 M
(3 FT) DEPTH

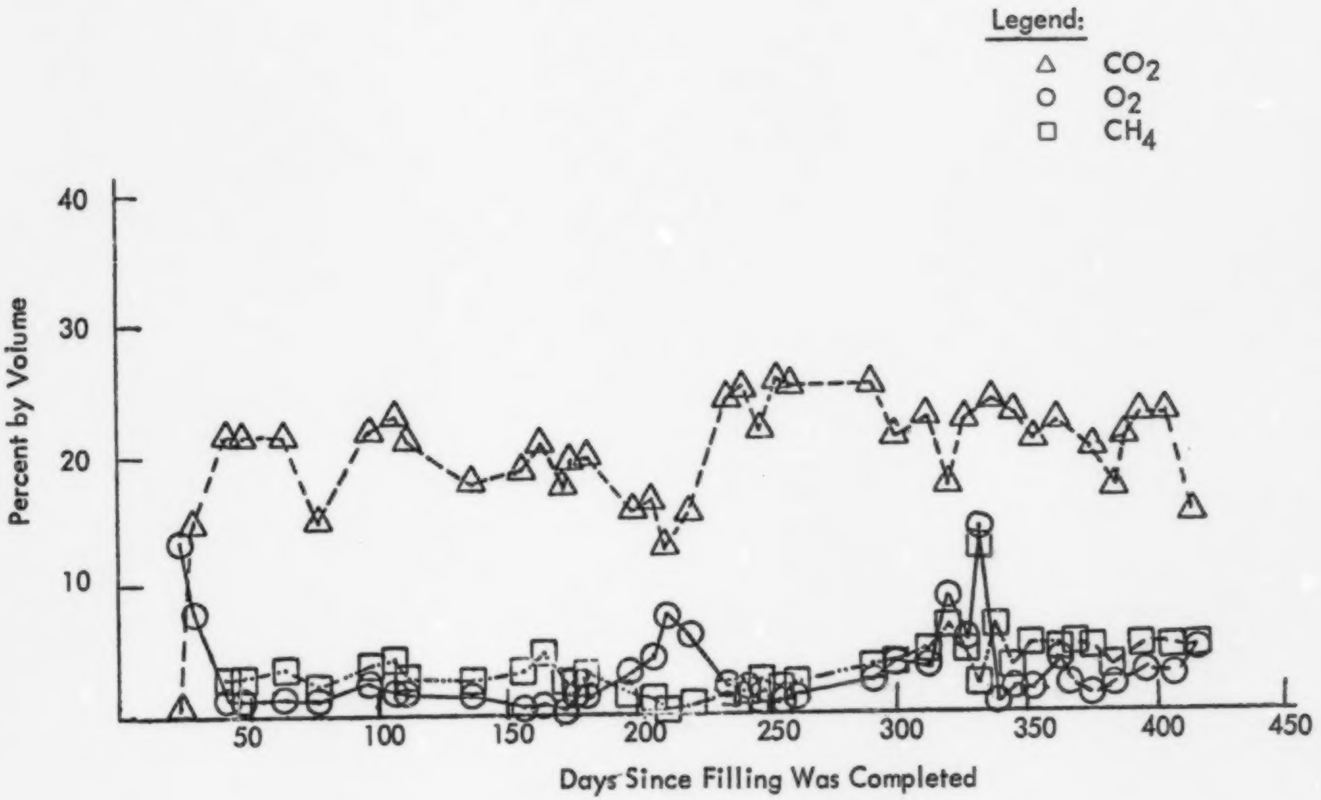


FIGURE 10-27
GAS ANALYSIS:
STATION 2 AT 2.4 M
(8 FT) DEPTH

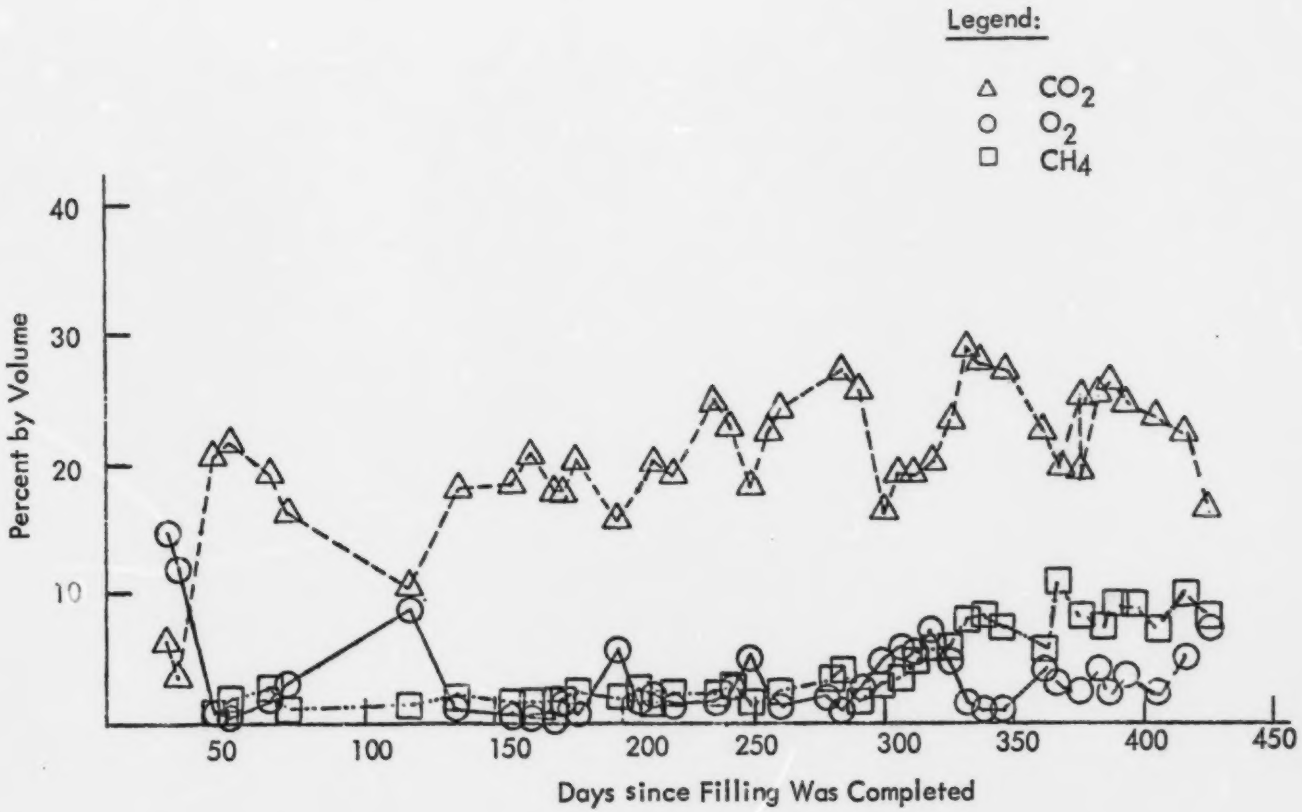


FIGURE 10-28
GAS ANALYSIS:
STATION 3 AT 0.9 M
(3 FT) DEPTH

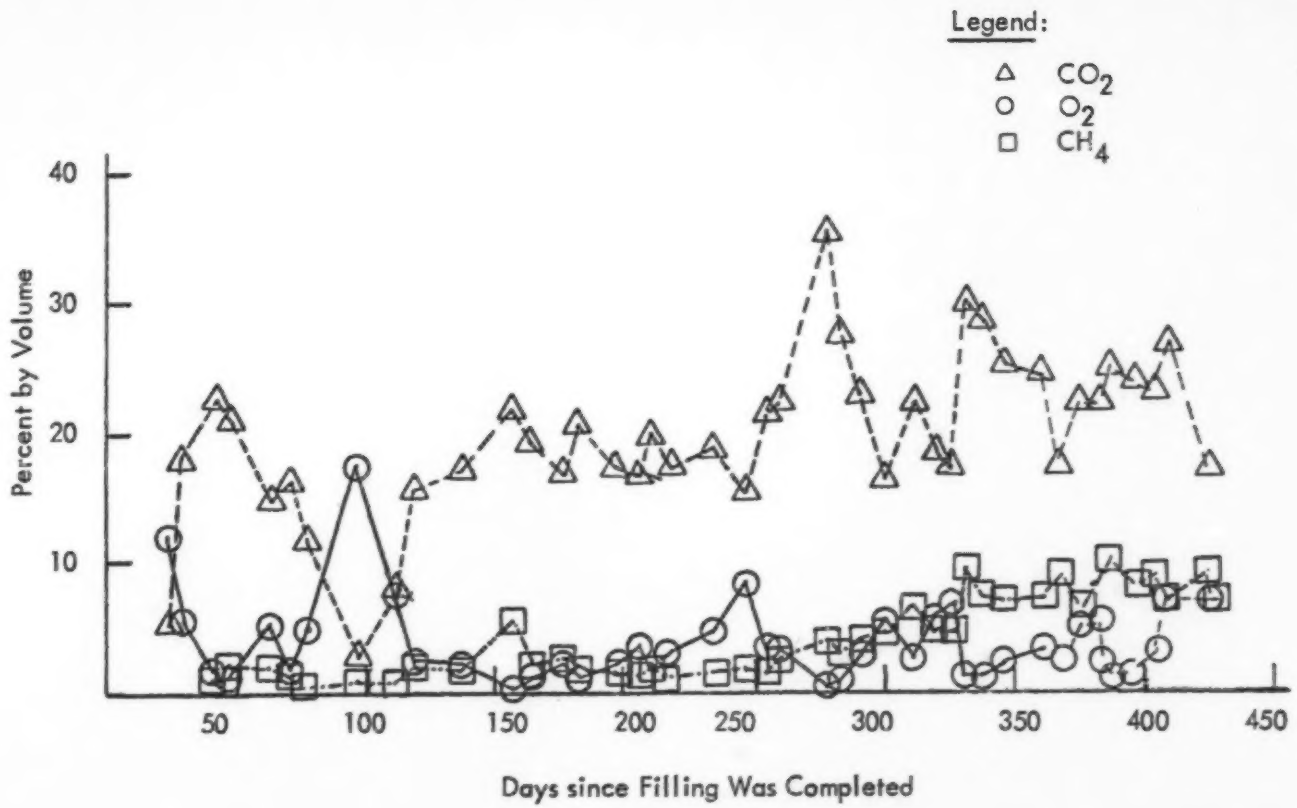


FIGURE 10-29
GAS ANALYSIS:
STATION 3 AT 2.4 M
(8 FT DEPTH)

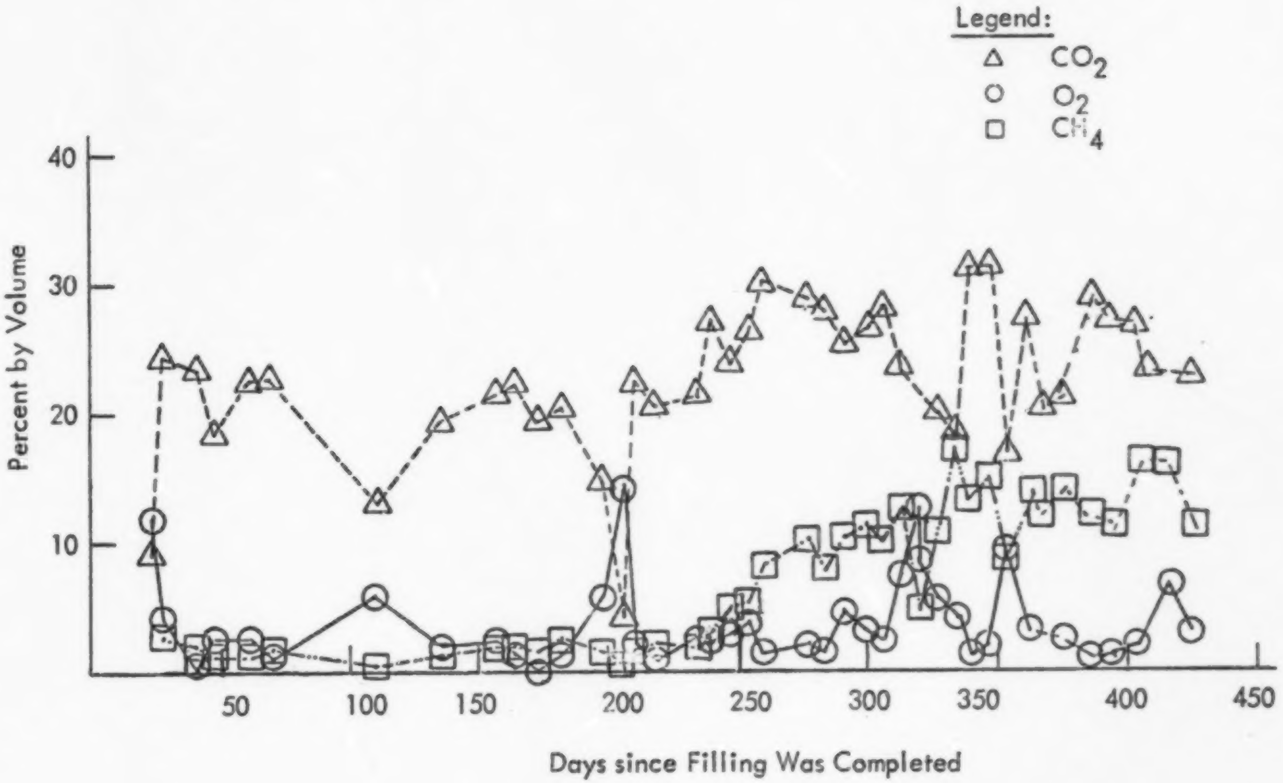


FIGURE 10-30
GAS ANALYSIS
STATION 4 AT 0.9 M
(3 FT) DEPTH

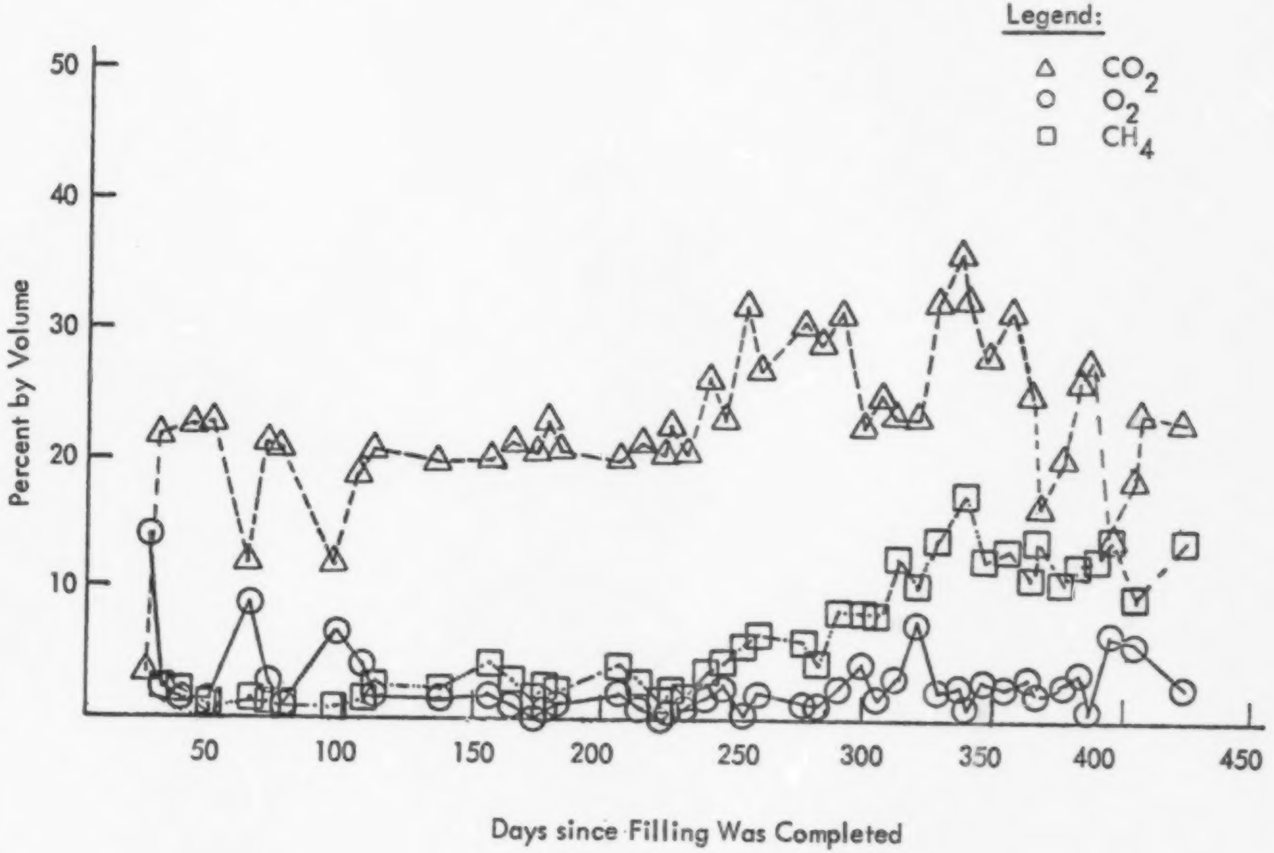


FIGURE 10-31
GAS ANALYSIS
STATION 4 AT 2.4 M
(8 FT) DEPTH

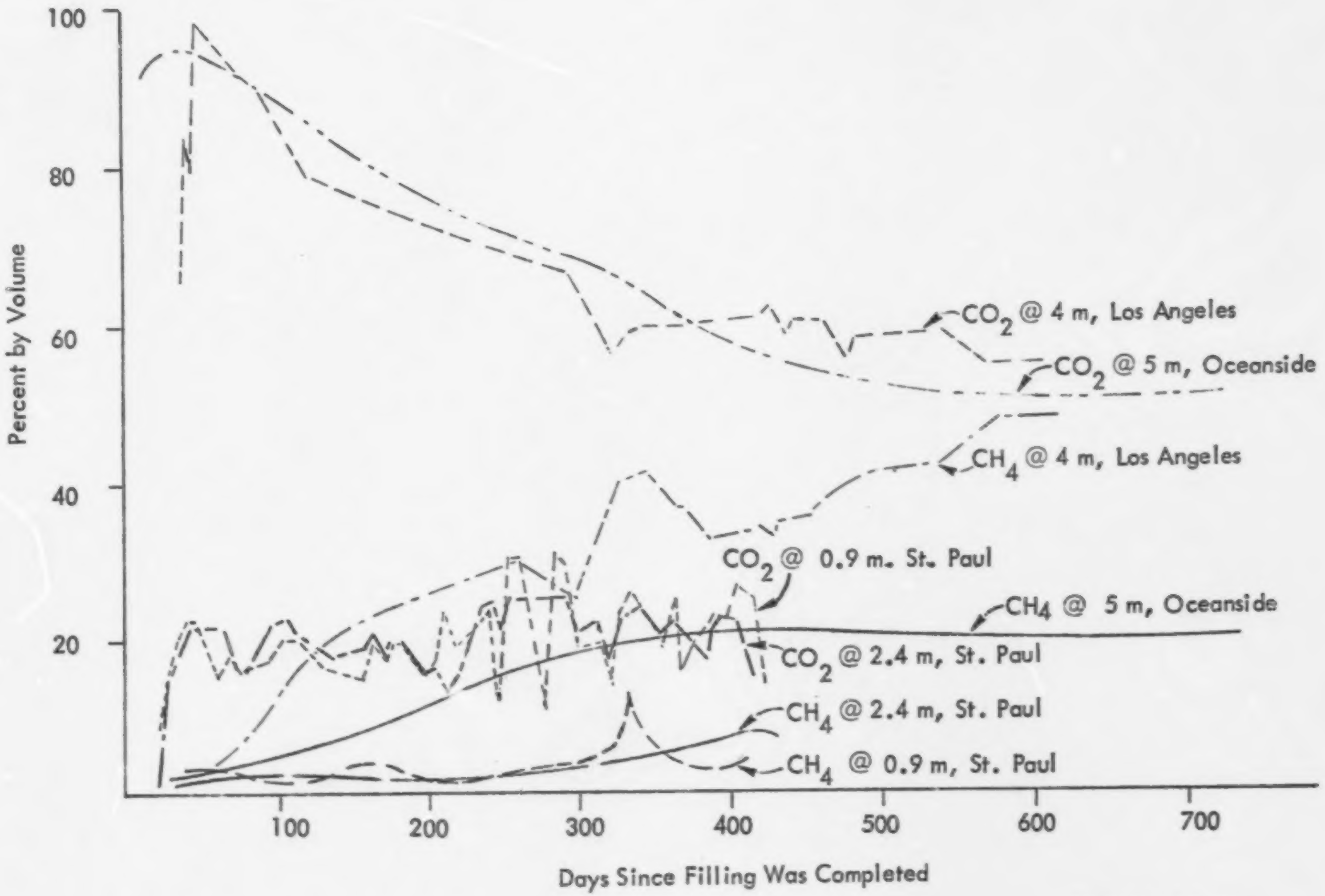


FIGURE 10-32
GAS COMPOSITION
COMPARISON

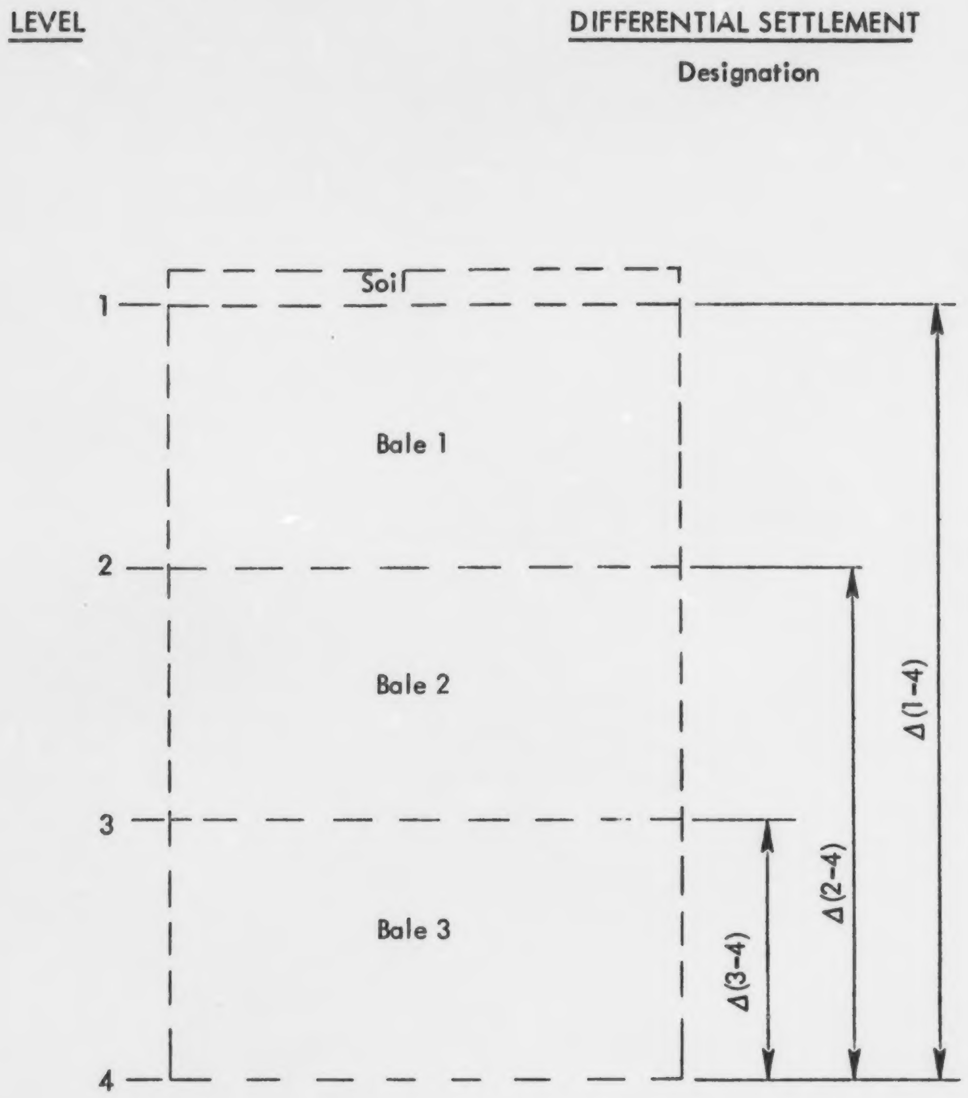
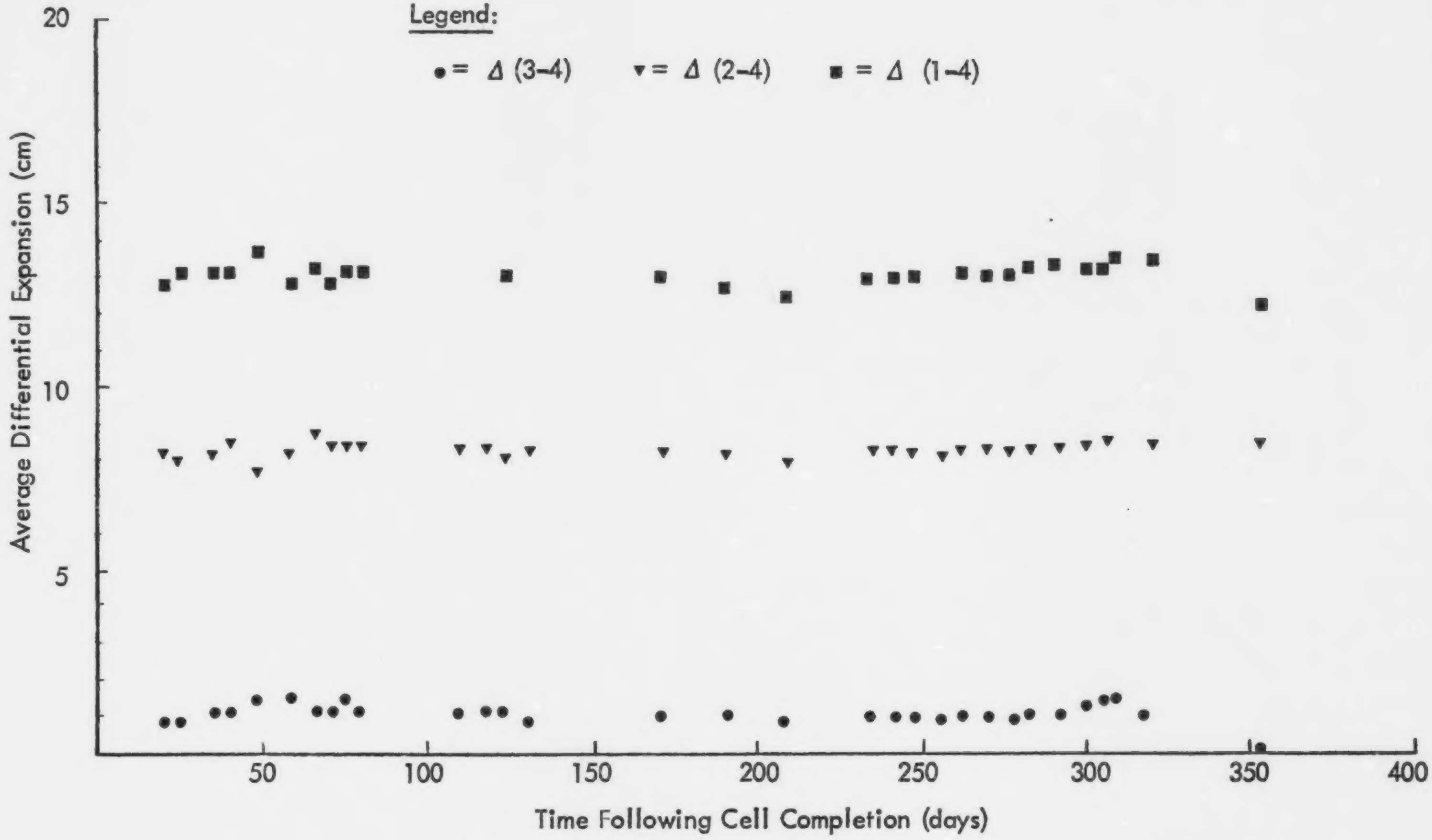

LEVEL
DIFFERENTIAL SETTLEMENT
Designation
Soil
1
Bale 1
2
Bale 2
3
Bale 3
4
Δ(1-4)
Δ(2-4)
Δ(3-4)

FIGURE 10-33
DIFFERENTIAL SETTLEMENT SCHEMATIC



NOTE: Settlement was measured between vertical benchmarks and averaged for each level for the 5 stations.

FIGURE 10-34
AVERAGE DIFFERENTIAL EXPANSION

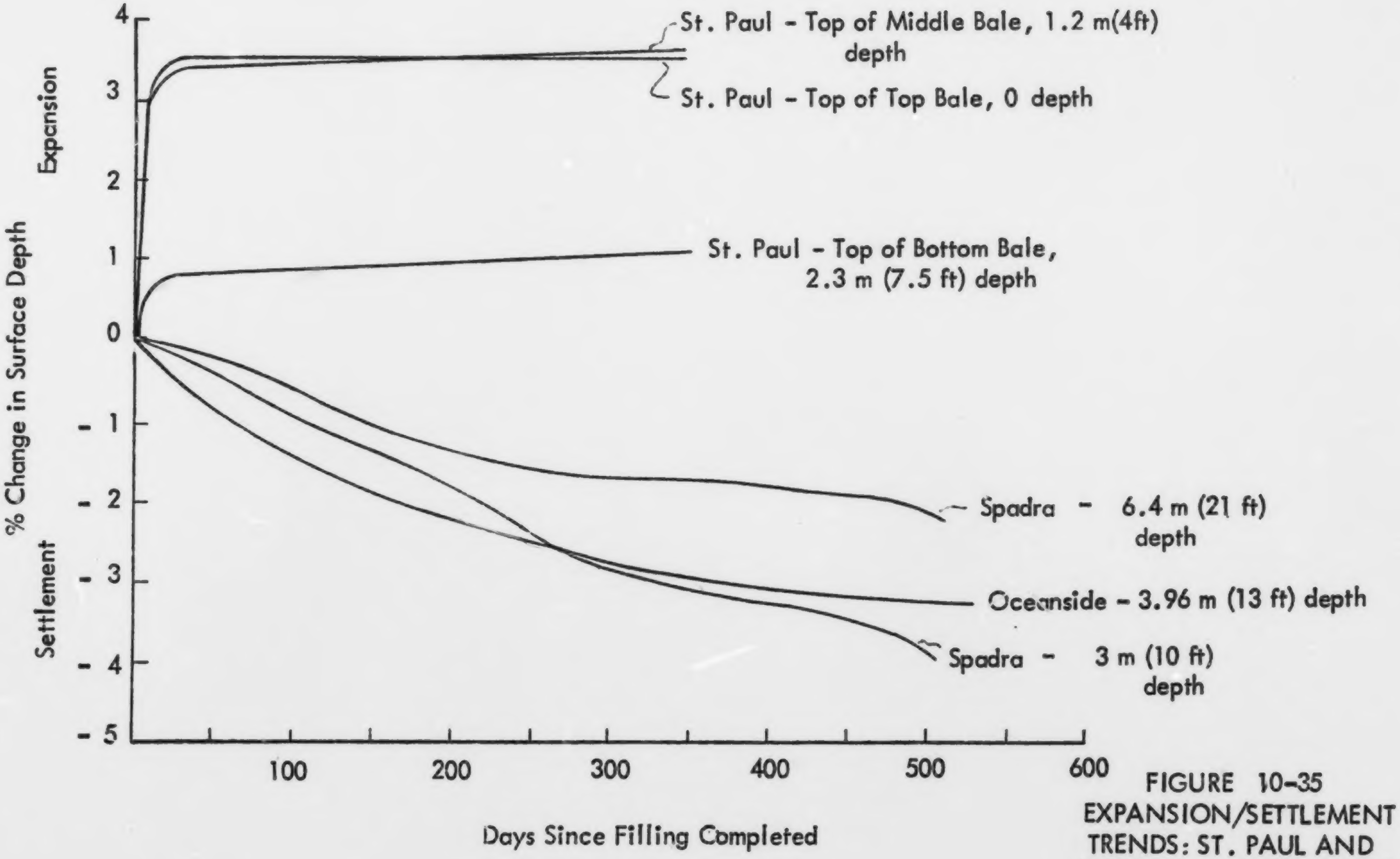


FIGURE 10-35
EXPANSION/SETTLEMENT
TRENDS: ST. PAUL AND
NORMAL LANDFILL CELLS

TABLE 10-7
BORE HOLE TEMPERATURE PROFILE

Depth, m	(ft.) Below Surface	Temperature, °C				
		Days Since Filling was Completed				
		180	415		730	
		New Landfill One Bore Hole	Test Cell Station 1	Test Cell Station 3	Old Landfill Bore Hole 1	Old Landfill Bore Hole 2
Ambient Air		6.1	4.4	6.1	6.6	8.3
Soil					Bale Surface	
0.46	(1.5)		13.2			
0.61	(2)	9.9				
1.22	(4)			9.9	5.0	10.0
1.83	(6)		12.1	15.4		
2.44	(8)	25.8				
2.75	(9)		20.9	28.1	12.1	13.8
3.05	(10)					14.3[a]
3.36	(11)		24.2	29.2		
3.66	(12)	34.7				
4.27	(14)				24.8	
Average		23.5	17.6	20.7	14.0	12.7

[a] Bottom soil.

fill material.

b. Organic Content. Organic content increased with depth in the newest fill, and decreased slightly with depth in the test cell intermediate age fill (Table 10-8). The intermediate soil layer in the old fill, a sandy-clay loam, had a negligible organic content. Immediately overlying it was a layer of paper waste of relatively high organic content.

The average organic content of the solid waste (excludes soil) in each borehole showed no discernable trend. In normal landfills, the organic content would be expected to decrease as the age of the landfill increased due to decomposition. A decreasing average borehole organic content was found as age increased during a two-year period (equivalent to St. Paul fill ages) for the test cells and landfill (with and without sludge) in Oceanside, California.

c. Moisture Content. Moisture content decreased with depth in Station 3 of the test cell and in Borehole 1 of the old fill (Table 10-9). Moisture content increased with depth in the new fill, in Station 1 of the test cell, and in Borehole 2 of the old fill. The intermediate soil layer in the old fill had a significantly lower moisture content than that of the overlying paper layer. Average moisture content remained essentially the same with age of the fill.

Moisture content is dependent on four factors (assuming no aquifer interaction): (1) weather, (2) topography, (3) permeability of fill, and (4) composition of fill.

All three areas experienced the same weather conditions. The finish topography is flat for all three areas. The test cell was bermed to prevent runoff. The different trends in moisture content may be explained as a variation in factors 3 and 4 above. The landfill areas would have drainage flowing on and off with a minor net drainage change or percolation difference from the test cell.

d. Decomposition. The decomposition of new versus older bales was examined qualitatively during the core drilling. Changes related to decomposition such as color, readability of printed matter (paper print, can and bottle labels, etc.) and material structure were not observed in the test cell core samples (415 days old). The colors were true (as in the waste when baled) and printing was readable. The newly placed bales also were natural in color and had readable printing. The paper waste from old bales (730 days old) tended to be easily pulled apart indicating some structural change. Overall, the difference between the newer (180 days old) and older (730 days old) waste bales was the slight structural change.

TABLE 10-8
BORE HOLE ORGANIC CONTENT[a]

Depth, m (ft.) Below Surface	% Dry Weight				
	Days Since Filling was Completed				
	180	415		730	
	New Landfill	Test Cell		Old Landfill	
	One Bore Hole	Station 1	Station 3	Bore Hole 1	Bore Hole 2
Soil				Bale Surface	
0.46 (1.5)		73.1			
0.61 (2)	36.9				
1.22 (4)			68.3	62.1	52.5
1.83 (6)		32.9	58.7		
2.44 (8)	65.2			29.3	
2.75 (9)		35.2	58.8	47.5	61.0
3.05 (10)					1.7[b]
3.36 (11)		60.0	60.7		
3.66 (12)					
4.27 (14)				57.5	
Average	54.5	50.3	61.6	49.1	38.4

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[a] See Table 10-2, p. 139 for organic content determination method.

[b] Bottom soil.

TABLE 10-9
BORE HOLE MOISTURE CONTENT

Depth, m (Ft.) Below Surface		% Dry Weight				
		Days Since Filling Was Completed				
		180	415		730	
		New Landfill	Test Cell		Old Landfill	
		One Bore Hole	Station 1	Station 3	Bore Hole 1	Bore Hole 2
Relative Humidity		100%	100%		100%	
Soil						
0.46	(1.5)		26.6			
0.61	(2)	35.6			Bale Surface	
1.22	(4)			88.9	96.5	22.1
1.83	(6)		54.3	34.2		
2.44	(8)	28.6			39.2	
2.75	(9)		39.8	24.8	40.3	62.7[a]
3.05	(10)					14.9
3.36	(11)		40.9	35.8		
3.66	(12)	63.9				
4.27	(14)				56.4	
Average		42.7	40.4	45.9	58.1	33.2

[a] Bottom Soil.

SECTION 11

GLOSSARY

Term	Definition
Ability	Statistical measure of production rate. Ability of a system is measured as a probability distribution of production rates.
Accessibility	Statistical measure of production time availability. Accessibility of a system is measured by the maximum number of hours a day that the system can be scheduled for production.
Activity Network	Schematic visualization of the sequential states occupied by a given machine.
Balefill	A land disposal site that receives baled solid waste, with or without binding, for disposal on land by an engineered method in a manner that minimizes environmental hazards by stacking the highly compacted bales to achieve the smallest practical volume, and applying and compacting cover material on the top of the bale lift at the end of each operating day.
Baler	A machine used to compress solid waste, primary materials, or recoverable materials, with or without binding, to a density or form which will support handling and transportation as a material unit rather than requiring a disposable or reusable container. (Source: WEMI Baler Subcommittee).
Baler Cycle	The start-to-finish sequence of operations by the baler that produces one solid waste bale.
Baler Feed Solid Waste Samples	A nine-kilogram composite sample of unbaled solid waste received from collection vehicles and obtained at daily intervals during the five-day study. The sample was composed of waste materials accumulated during bi-daily solid waste sortings, and was composed to correspond with percentages of constituents found in the bi-daily sortings.
Baler Liquid Squeezing Samples	Liquid samples obtained once or more per day during the five-day study; collection occurred directly below the baler base. Both unstrained and strained (through mesh screening) samples were taken.
Baler Operator	The baling plant employee responsible for control of the conveyor, scale, and baler equipment operation (see Control Tower Operator).

Term	Definition
Control Tower Operator	Employee responsible for supervising bale production, cycling the baler, measuring the baler charge, allowing transports to switch on time, and keeping the conveyor full.
Conveyor	Two conveyors are employed at the baling plant to move solid waste from the unloading area to the scale platform. The first conveyor is horizontal, and the second is inclined; both are 2-bar slat conveyors.
Forklift	Machine that removes bales from the bale discharge platform inside the baling plant; these bales are composed of special materials such as corrugated paper or selected metals. The forklift also removes broken bales from the platform and deposits them onto the incoming solid waste pile, as well as lifts up the edge of the loading platform to allow the transport vehicle to fit under its edge.
Gantt Chart	A schematic method of illustrating relative times occupied by processes within a given sequence.
Gate Attendant	Employee responsible for directing incoming traffic and charging and collecting fees from incoming solid waste collection vehicles.
Interference	Statistical measure of the time one machine in a network is forced to be idle while waiting for a second machine to complete its task.
Loader	Mobile apparatus used in the baling plant to pile incoming solid waste, load refuse onto the horizontal pit conveyor, mix solid waste, scrape the unloading floor and sort large metal objects and corrugated paper. The loader operator is the employee responsible for running the loader. A small "bobcat" loader is also employed at the baling plant for general operations.
Loader Operator	Employee responsible for operation of the forklift and general purpose loader inside the baling plant.
Maintenance Man	Employee keeping baling plant equipment in operating condition, repairing minor breakdowns, used for filling-in for missing personnel, and assisting in transport-vehicle rigging and floor sweeping.

Term	Definition
Platen	A metal plate pushing solid waste across the scale and into the baler charging box.
Pusher	Hydraulic apparatus moving baled solid waste onto transfer vehicles. Pusher one is activated every baler cycle, while pusher two is operated every other baler cycle.
Queueing	Procedure of organizing and processing vehicles in waiting lines. Applied to describe where one or more collection trucks are attempting to or actually are unloading solid waste at the baling point.
Reliability	Statistical measure of ability to maintain production. Reliability of a system is measured as the probability distribution for the fraction of time producing divided by scheduled operating time.
Rigging	Procedure by which bales are covered within transport trucks prior to departure from the baling plant. Nylon mesh curtains are pulled over the bales and attached to the bottom of the truck trailer bed with hooks. The tailgate is placed and secured following curtain rigging.
Segregator	Employee responsible for separating corrugated paper and selected metals from the baler feed solid waste.
Utilization	Statistical measures of the use made of each machine in a network. To obtain percent utilization of a machine for a given state, the amount of time spent in that state per cycle is divided by the machine total cycle time.

SECTION 12

METRIC TO ENGLISH UNIT CONVERSION TABLE

Metric		Measure	English[a]
		LENGTH	
unit	abbreviation	number of meters	approximate U. S. equivalent
myriameter	mym	10,000	6.2 miles
kilometer	km	1,000	0.62 mile
hectometer	hm	100	109.36 yards
dekameter	dam	10	32.81 feet
meter	m	1	39.37 inches
decimeter	dm	0.1	3.94 inches
centimeter	cm	0.01	0.39 inch
millimeter	mm	0.001	0.04 inch
		AREA	
unit	abbreviation	number of square meters	approximate U. S. equivalent
square kilometer	sq km or km^2	1,000,000	0.3861 square mile
hectare	ha	10,000	2.47 acres
are	a	100	119.60 square yards
centare	ca	1	10.76 square feet
square centimeter	sq cm or cm^2	0.0001	0.155 square inch
		VOLUME	
unit	abbreviation	number of cubic meters	approximate U. S. equivalent
dekastere	das	10	13.10 cubic yards
stere	s	1	1.31 cubic yards
decistere	ds	0.10	3.53 cubic feet
cubic centimeter	cu cm or cm^3 also cc	0.000001	0.061 cubic inch

METRIC TO ENGLISH UNIT CONVERSION TABLE (Cont.)

Metric		Measure	English[a]		
		CAPACITY			
unit	abbreviation	number of liters	approximate U. S. equivalent		
			cubic	dry	liquid
kiloliter	kl	1,000	1.31 cubic yards		
hectoliter	hl	100	3.53 cubic feet	2.84 bushels	
dekaliter	dal	10	0.35 cubic foot	1.14 pecks	2.64 gallons
liter	l	1	61.02 cubic inches	0.908 quart	1.057 quarts
deciliter	dl	0.10	6.1 cubic inches	0.18 pint	0.21 pint
centiliter	cl	0.01	0.6 cubic inch		0.338 fluid ounce
milliliter	ml	0.001	0.06 cubic inch		0.27 fluid dram
		MASS AND WEIGHT			
unit	abbreviation	number of grams	approximate U. S. equivalent		
metric ton	MT or t	1,000,000	1.1 tons		
quintal	q	100,000	220.46 pounds		
kilogram	kg	1,000	2.2046 pounds		
hectogram	hg	100	3.527 ounces		
dekagram	dag	10	0.353 ounce		
gram	g or gm	1	0.035 ounce		
decigram	dg	0.10	1.543 grains		
centigram	cg	0.01	0.154 grain		
milligram	mg	0.001	0.015 grain		

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[a] Multiply metric units by the U. S. equivalent values to get English equivalent units.

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